# ELEMENTARY GENERAL SCIENCE

## A BOOK FOR TEACHERS

A. G. HUGHES

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# ELEMENTARY GENERAL SCIENCE

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# ELEMENTARY GENERAL SCIENCE

## A Book for Teachers

BY

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# PREFACE

This book, with its companion books for the use of pupils (*Elementary General Science*, Books I–III, by Hughes and Panton), has been written primarily with a view to helping teachers in the Senior (now Secondary Modern) schools created by the reorganization of elementary schools. It is hoped that it will also prove useful to science teachers in other types of schools and to students in training colleges.

The books are founded on the thesis that the central feature of the school curriculum should be a study of the process of living. It then follows that science in schools should be a study of the scientific aspect of this process. The single topic —Living—acts as a unifier. For science teachers, the study of this topic makes it possible to present both physical and biological science, not as a collection of separate branches but as a coherent unity which forms part of a larger whole. Science is then seen in its proper perspective as one important facet of a unified curriculum.

I wish to acknowledge my indebtedness to my former training college students in Leeds and Isleworth, and to many teachers of science in London with whom I have had the privilege of discussing the problems of science teaching during the past twelve years.

I am also particularly indebted to Mr. E. H. Betts, B.Sc., Mr. G. H. Leslie, B.Sc., Mr. G. Lilley, M.A., and Mr. J. H. Panton, M.A., for much friendly encouragement and criticism in connexion with the present exposition of my views.

As an officer of the London County Council, I am required to state that the Council is in no way responsible for the views expressed in this book.

A. G. HUGHES.

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# ELEMENTARY GENERAL SCIENCE

## CHAPTER I

## Science in Senior Schools

### Why should we teach Science?

It is usual to begin a book on the teaching of any subject with a discussion of the reasons why we should teach it. Why, then, should we teach science? The answer is simple and straightforward. We ought to teach science because it is and always has been one of the fundamental necessities of mankind. We are not using the term "fundamental necessity" in any material sense, for obviously there was a time when man was able to satisfy his simple material needs without the aid of science. But probably there never was a time when he did not feel the need for some intellectual mastery of the working of Nature. Confronted with natural phenomena, he could not help asking How and Why, and he could not help framing hypotheses as answers to his questions. The earliest hypotheses we now call superstitions; in time they gave way to new and more satisfactory explanations which in turn were again superseded. In this way science, as we know it, has been gradually built up, and the process is, of course, still continuing. Science, then, is the inevitable result of one of the natural reactions of man to his environment; it is, as Nunn says, one of the great traditions of the human spirit and its claim to a place in any scheme of general education rests on this fact. It is not more or less important than any other great human tradition—art, craft, literature, mathematics, or music; each is a fundamental necessity in the sense that man has been impelled by his own nature to develop it. Without any one of them, life would be immeasurably poorer. We conclude therefore that the reason for teaching science is not different from the reason for teaching the other main subjects of the curriculum; the pursuit of science is one of the important means by which man has enriched his intellectual interest in life.

### The Scientific Interests of Children.

This great movement, the gradual increase in intellectual interest and control, we see clearly in the history of the race, but we can also see it repeated in the early history of every normal individual. Considering science in particular, we notice how babies react to their environment with crude expressions of curiosity and wonder; as soon as they can speak, they express themselves by ejaculating words, and by the third year they are asking How and Why questions. Then we know how their "science" is progressing.

There is one striking difference between the spontaneous science of children and the conventional science of text-books. Children's science is undifferentiated; that is to say, it is not divided into branches of science. It is important to remember that the division of adult science into branches is a comparatively modern development brought about by the growth of the subject and the consequent need of specialists for the purposes of research. Only a hundred years ago, it was possible for Faraday to carry out important researches in chemistry, metallurgy, and electricity; this would hardly be possible to-day. No senior-school pupil, however, is likely to become a research specialist, and even if he were, the proper basis for such work would still be a general understanding of science. There is, in fact, no fundamental reason why science in schools should be divided into branches. On the contrary, there is much to be said for the thesis that science, as opposed to selected branches of science, should form the subject of instruction up to and including a first B.Sc. degree. However that may be, there is no doubt that in considering what science we should teach in senior schools, it will be more profitable to turn to the spontaneous science of childhood than to the organized sciences of university courses.

What are the scientific interests of children? As we might expect, they are as wide in their range as those shown by the race in its development. No part of the environment is devoid of scientific interest to young children; questions are asked about everything. Readers who have young acquaintances between the ages of two and five will find it interesting and illuminating to keep a record of their spontaneous scientific interests as revealed in their sayings and questions. It is good to be reminded that there was a time when the schoolboy, now busy studying a matriculation course in sound, light, and heat, used to think about the wonders of the sky at night: it is important to be reminded that this same schoolboy is most probably carrying with him the relics of discarded hypotheses as to how he was made, though, as a result of examination requirements, there has probably been no time in school for him to gain any scientific knowledge about protoplasm and cell growth.

## Syllabuses and the Limitations of Time.

Senior schools are free from the pressure of examinations, but shortness of time nevertheless constitutes a very real difficulty. While secondary- and central-school pupils have at least a four-year course, senior-school pupils under ideal conditions have only three years, and in point of fact, many of them have but two and a half. This difficulty is so serious that we shall have to refer to it on several occasions in later chapters. At the moment, we will concentrate our attention on the main feature of the problem: we have to show how it is possible to devise a three-year course in science for average children. This course, moreover, must be sufficiently comprehensive to appeal to the wide interests shown by children; it must, therefore, be wider than some courses now prescribed for matriculation.

The problem may well appear insoluble. If we approach science as a collection of branches, a mere enumeration of those branches which are generally recommended as suitable and desirable is perturbing. Physics alone comprises properties of matter, mechanics, sound, light, heat, magnetism and electricity; and to this list we must add chemistry, biology, geology, and astronomy. If we call magnetism and electricity one subject and omit branches which are often included under the names domestic science and hygiene, we have even then a course comprising ten " branches ". Many senior-school courses are arranged on some such basis, the syllabus in each branch being set out in a separate column and the whole called general science. There can only be one result from this columnar type of syllabus; the course proves impracticable and a note is added to say that selections must be made. With average pupils, there is not time in three years to teach satisfactorily even five separate sciences.

Some reformers have apparently felt uneasy about the columnar type of syllabus, and though they discuss science in its conventional watertight compartments, they recommend teachers to lose no opportunity of making cross-references from one subject to another. This is no more than a helpful palliative. The most it can do is to mitigate some of the harm done by what, in our opinion, is a fundamentally wrong approach to the subject; it may, for example, prevent some pieces of knowledge from remaining isolated in children's minds when they ought to be related. But so far from saving time, it probably consumes time, for not only have we to teach the separate courses, we must also teach how one course is here and there connected with another. There is no hope of solving the problem of science in senior schools until, resolutely turning our backs on branches of science and the columnar type of syllabus, we adopt a totally different method of approach.

### The Need for Coherence.

We have rejected the "cross-reference" device because it offers no satisfactory solution of our problem. There is no doubt, however, that the intentions of those who suggest it are sound, for they do at least recognize the need for giving children in senior schools some picture of science as a coherent whole. But they are working from the wrong end. Having unnecessarily isolated branches of science, they are trying to reunite what should never have been separated. What is required is some means of presenting science as a coherent whole, instead of a method which presents it piecemeal and then endeavours to join up the pieces. Of the many ways of making a counterpane, there are two which are fundamentally different: it can be made by weaving one piece, or it can be made by sewing together many small patches. The chief reform needed in science teaching to-day is the replacing of "patchwork" methods of teaching by a "one-piece" method. Before we can do so, we must decide upon a suitable pattern.

### The Biological Outlook of Young Children.

We have been led to this point by a consideration of children's spontaneous science which, as we have seen, is undifferentiated and comprehensive. The question now arises whether it has any pattern which may guide us in devising a school course. In other words, is there any germ of organization in children's science, or is it completely haphazard?

We suggest that from earliest years children's science is not devoid of at least a germ of organization. The inconsequence of children's questions about the world is more apparent than real, for the questions have one common source—the interest of the child in himself as a living being Young children, looking out on the world, feel themselves to be the centre of the universe; they tend to observe everything in relation to themselves. They are alive; they eat, drink, and grow; they move about and do things; they see, hear, and feel. All their experience is referred to these basic facts. Thus they are at once interested in things which move, for is not movement a sign of being alive? Wind and moving water, the sun and moon—all are thought to be alive as they themselves are alive. Children, we say, have an anthropomorphic view of Nature:

"The sun has coal for its supper; I've seen the coal in a field."

"The sun is a bird; it's got wings."[1]

The same ego-centric tendency manifests itself in many other ways. Young children, for example, are much more interested in animals than in plants, for animals are so obviously like themselves. They are fascinated by babies of any species and are continually asking about the problem of growth:

"How do they make babies?"
"Was I ever as little as that?" (pointing to toe).
"Why do worms have eggs?"

They also take a great interest in their own bodies:

"What is it? What is it for?" (pointing to navel).
"Why am I not in two all the way up?"
"Why can you hear behind you? You can't see behind you."

Though their view widens as they grow older, they continue to see things in relation to human beings. They are, we may say, still biologically-minded. Thus everything, in their view, must have been made by people:

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[1] These illustrations of children's "science", and most of the others quoted in this chapter, are taken from *The Scientific Interests of a Boy in Pre-school Years*, by Two Parents, Forum of Education, Vol. VI, pp. 17–37.

"Who puts the leaves on the trees?"

"What makes the sun so red? I expect they put some red in it."

"Who first made the world? He must have had some ladders held up by electricity."

"How are rivers made? . . . Oh! I see; first you build a hill and that saves carrying the water."

"I suppose snow is really rain and they mix cream with it to make it white."

The whole universe, with special reference to themselves and human beings, is the subject-matter of children's science. No line is drawn between physical and biological science; still less is there a division into branches. The whole subject, though loosely knit together, is not altogether haphazard and unorganized, for it has one unifying centre of interest—the child himself as a living being. As this interest develops, he begins to ask questions not only about himself but also about other things which are alive or which seem to be alive, and about the causes and results of their activities.

## Science in Infant, Junior, and Senior Schools.

The spontaneous "science" of little children is clearly the proper basis for the study of Nature in infant and junior schools. The work should not be confined to the study of plants nor indeed to animate Nature. Things which move—children themselves, animals moving in air, water, and on land; toy aeroplanes, trains, and boats; rain, water, and wind; india-rubber balls and growing plants—this is the kind of topic suitable for these early stages. Courses will consist largely of the working out of projects, that is, they will be based on children's actual experiences—the keeping of animal pets, the growing of plants, outdoor rambles, children's games, and the daily practice of hygiene. In these ways, the pupils' natural interest in the whole realm of science will not only be kept alive, it will also be deepened by the acquirement of a great deal of knowledge. We now approach the senior-school stage.

The science of the senior school should be a development of the nature study done in the junior school, for there is no sudden change in mental powers at the age of eleven which should lead us to make any sudden change in our conception of the subject. There is nothing in child nature at this age which need tempt us, for example, to adopt a columnar type of syllabus and a "patchwork" course which we have already rejected on account of time and other limitations. And neither at this nor at any other age do the interests of boys and girls diverge so widely as to justify us in confining girls henceforward to physiology and hygiene, and boys to physics and chemistry. There has, however, been a gradual growth among both boys and girls in general intellectual ability, and there is, therefore, some justification for giving increasing emphasis to rational explanation. For this reason, and particularly because in less than three years the pupils will be leaving school, it is desirable to make the senior-school course more systematic than the junior-school course has been; it should be more closely knit together, more definitely coherent. How can such a course be devised? How can we make science both comprehensive and coherent? How can we adhere to our general principle that children's science must be based on actual experience in the outside world and at the same time make it systematic? The two sets of qualities seem to run counter to one another. Comprehensiveness and actual experience seem to indicate a medley of material in which coherence and system can have little part.

## The Topic Method.

The most promising suggestion is one which has gained some ground in senior schools under the title of the "topic method". Using this method, we approach the numerous items of the various systematic branches of science by studying a small number of important everyday topics, such as, Heating our Homes; Washing our Clothes; Useful and Harmful Insects; The Soil of our Gardens; The Sun and Moon. This plan certainly reduces the incoherence of some old-time courses in which single lessons on such unrelated subjects as Convection, Soap, Flies, Chalk, followed one another with gay inconsequence. It also avoids many of the defects of courses based on the columnar type of syllabus. It is certainly not a crazy " patchwork " method, though as often practised, it is hardly a " one-piece " method. In order to make the " topic method " conform to our general principles it is necessary to find some single topic which will embrace the whole of science.

Now we have already noticed that the science of very young children is actually based on such a single topic—The Process of Living. We suggest that this is also the most suitable topic for science in senior schools. By adopting it, we not only bring the science of these schools into line with the nature study of junior schools, but we also bring science into line with other subjects of the curriculum. For example, in geography and history we have a unifying thread which runs through the whole course. We do not teach branches of these subjects; we try to give children some more or less coherent idea of how mankind lives and has lived on this planet. Fundamentally, there is only one topic underlying the whole curriculum; it is the topic of Living. When studying geography, we look through the spectacles of geographers at life in space; when studying history we look through the spectacles of historians at life in time; when studying science we should again look at the same topic but through the spectacles of men of science. Our science course would then consist of one main theme only—Living—and all the science taught—astronomy, biology, chemistry, geology, physics—would grow naturally and inevitably out of it.

Such a scheme would not only enable us to make science itself coherent and intelligible, it would also help us to devise a unified curriculum in which science and all the other subjects we teach fall naturally and inevitably into place. Such a unification is necessary in order to reduce the overcrowding of the curriculum; it is indispensable if we are to give our pupils in school anything approaching a coherent view of life.

## The Science of Living.

We argue therefore that science in schools should be the Science of Living, and we suggest that this is a fundamental general principle applicable to schools of every type. This may sound an extravagant claim and we hasten to add that there are innumerable methods of putting this general principle into practice. The method described in this book and worked out in detail in the Pupils' Books[1] is only given as an illustration of one way in which it is possible to apply the principle to the teaching of science in senior schools. This method will be described in general terms in the next paragraph and in more detail in Chapters II, III, and IV.

The Science of Living is admittedly a very complex subject, and whatever method of presenting it to average children is devised, it will be necessary to start with a very simplified version of life. For that reason, we suggest first that the course, while being progressive, should also be concentric. Second, we suggest that the main topic should be subdivided into four smaller ones: *Breathing*, *Feeding*, *Moving*, and *Sensing*. In subdividing our topic in this way, it should be noticed that we are not sacrificing the unity of our scheme, for our sub-topics are intimately related. For example:

> We breathe in order to obtain oxygen for the oxidation of food by means of which energy is released to enable us to move; in making these movements we are guided by news of the outside world which we get through our senses.

---

[1] The Pupils' Books are: *Elementary General Science*, A Course for Boys and Girls, Books I, II, and III, by Hughes and Panton (Blackie). Most of the illustrative quotations in subsequent chapters of this book are taken from these Pupils' Books which are referred to by the letters, E.G.S.

Or, looking at the unity another way:

We get news by sensing; this enables us to make the appropriate movements, so that we may breathe and feed.

Moreover, the four activities we have chosen contribute to the process of living at every level. Even plants must partake of air and food, and in getting adequate supplies, they must move in response to environmental influences to which they are sensitive. The same four activities are more obviously developed in animals, and they are most easily appreciated by children as elements in their own lives. Human life is therefore always taken as the starting-point. We begin by studying how we ourselves breathe and feed; how we move ourselves and other things about by the aid of our living machinery; and how we are guided in making these movements by sensing. From this starting-point, we go on first to examine the same four vital activities in lower animals and plants; second, to study how man has by scientific invention increased the effectiveness of these four vital activities in his own life. Thus we emphasize both the solidarity and the diversity of life; we recognize, on the one hand, our kinship with less developed forms, and, on the other hand, our kingly power over them; and running through the whole course there is necessarily a continuous study of the physical environment in which we live and move and have our being.

**Books for Reference:**

*Science in Senior Schools*, Board of Education (H.M.S.O.).

*Suggestions for the Consideration of Teachers*, Chapter VI, *The Study of Nature*, Board of Education (H.M.S.O.).

*Teaching Science in Schools*, J. Brown (Univ. of Lond. Press).

*The New Teaching*, edited J. Adams, Chapter X, *Science*, T. P. Nunn (Hodder & Stoughton).

*Science Teaching*, F. W. Westaway (Blackie).

## CHAPTER II

# A First-year Course

The work suggested for the first year consists of a preliminary survey of our topic in its four aspects—Breathing, Feeding, Moving, and Sensing. Broadly speaking, the pupils learn in the first year that carbon dioxide is made by all living things as they breathe; that carbon dioxide is used as food by green plants in sunlight, thus producing energy-giving food not only for the plants themselves but also for animals; that the energy obtained from this food is used when living things move; that animals move by means of bodily levers. They then learn how man has extended his natural levers by inventing artificial ones; how when moving, living things are guided by news of the outside world they get by sensing and particularly how animals are guided by seeing and hearing.

**Introduction.** (*E.G.S. I*, Chapter I, *The Science of Living*, pp. 1–4.)

One very common method of introducing a science course is by means of a series of exercises designed to promote accurate measurement. This practice is apparently founded on the dictum: Science is Measurement. In the advanced stages of science this is true, and the degree of maturity in a branch of science can to some extent be gauged by the extent to which it makes use of mathematical formulæ. But children's science is not measurement except here and there, and then the necessary measurements are of a primitive kind. The amount of strictly quantitative work which is desirable or possible in senior schools is very small, and very little of the so-called introductory practical work in measurement is relevant to a senior-school science course. Some of the conventional exercises may be useful, but their place is in the mathematics course. Some special measuring instruments may be used as the science course proceeds, but the best time to introduce them is when they are needed for a specific scientific purpose. A formal lesson, for example, on the construction, care, and use of the chemical balance does not appeal to the interests of average children, and is, in fact, not necessary.

A second method of introducing a science course is by means of a lesson, or a series of lessons, designed to give children an idea of what science is. This is sometimes done in the supposed interests of scientific method, but such a practice is surely in itself the negation of scientific method. Children need data before they can appreciate what science really is, and these data they can only obtain as the course proceeds. An appreciation of the meaning of science and scientific method grows gradually; it is something which may be looked for at the end but not at the beginning of the course (see Chapter X).

It is, however, sound policy to give pupils a bird's-eye view of the course at an early stage. It may, for example, be done when introducing the idea of a class question book (see p. 100). The ultimate aim of the science course is to provide answers to as many as possible of the How and Why questions which pupils may ask, but even beginners will appreciate that it is necessary to introduce some order into the medley. We therefore suggest dividing things into living and non-living, taking a rapid glance at the most puzzling question ever asked—What is life? "Men of science cannot yet answer it and perhaps they never will. But they have found out many interesting facts about living things, and they can teach us a great deal which will help us to live healthier and more useful lives. This is why we study science; it helps us to make our lives more interesting, more healthy, and more useful." (*E.G.S. I*, p. 3.)

Thus in a few words we try to give pupils some explicit notion of why they study science in school. This should be kept before the pupils throughout the course; a good plan is to have a card prepared in the art room and display it prominently in the science room:

SCIENCE HELPS US TO MAKE OUR LIVES MORE INTERESTING, MORE HEALTHY, AND MORE USEFUL

A brief comparison of human beings with a statue throws the main lines of our proposed course into high relief. "You can do some very important things which the statue cannot do. Indeed, as long as you are alive, some of these things you must do. You must breathe and feed; you must move; and in the course of your daily life you cannot help seeing and hearing, tasting, smelling, and feeling. These are the special subjects we shall study, and you will find that our science lessons will lead us to ask many questions, not only about ourselves but also about other living things, and about the non-living things all around us." (*E.G.S. I*, pp. 3-4.)

If such an introduction is attempted, it must be done quickly and with a very light touch, for the pupils have come to the science room to learn science. They are eager and expectant; they have their own ideas of what science is—*experiments!* In actual practice, it may be good policy to begin with experiments in the first half-hour.

**Breathing.** (*E.G.S. I*, Chapter II, *Breathing*, pp. 5-20.)

SUMMARY

Rates of breathing—The ocean of air—The air we breathe out—Carbon dioxide—Noses and no noses—Do underground creatures breathe?—Do water-dwellers breathe?—Do plants and trees breathe?—The importance of clean air.

Breathing is one of those phenomena to which we are so accustomed that it has become commonplace. This makes it appear at first sight a dull subject with which to open our course. There is, however, at least one aspect of breathing which a few years ago was fascinating enough to attract a crowd in a market-place. A vendor of "health-giving" tablets arrested attention by asking people if their breath was good and inviting them to test it. A willing victim was told to breathe out through a straw into a clear liquid in a glass tube. To his consternation, it turned cloudy. A tablet (in reality an acid drop) was then dropped in. We will draw a veil over the subsequent proceedings. The difference between air breathed in and air breathed out can be made a good starting-point for our course.[1]

We must *tell* our pupils that men of science know of no other gas which turns limewater cloudy and that its name is carbon dioxide. The formula $CO_2$ would be quite out of place here; time would be better spent in making sure that the pupils grasped the meaning of the word "gas". That which comes out when you "turn the gas on" is only one kind; the gas the dentist uses is another kind. Lessons on solids, liquids, and gases at this stage would merely result in labouring the obvious, and there will be many incidental opportunities during the course for pointing out the significant differences between the three states of matter. But it comes as a revelation to children to learn that there are various kinds of airy stuff all of which move about freely like air and yet are different. To make the idea still clearer, it might be worth while to show pupils some coloured gases, e.g. nitrogen dioxide or chlorine, streaming about.

A simple study of carbon dioxide may now follow. There is a tendency in science lessons to over-emphasize the dangerous character of this gas and to understate its usefulness. It is true that it is the dreaded choke-damp of coal-mines, and that by Act of Parliament the air in mines must not contain more than 1¼ per cent. It is not so generally known that in a crowded room the percentage of carbon dioxide has never been found to exceed 1, and that miners, divers, and men in breweries often breathe, apparently with impunity, air which contains this amount. Carbon dioxide is too often described as if it were the chief ingredient of "bad" air in rooms. The confusion probably arises from the fact that, in an ill-ventilated room, air contains deleterious and bad-smelling substances which increase *pari passu* with the amount of carbon dioxide. The gas is useful in the following ways:

---

[1] This is not strictly in accordance with the sequence of subject-matter in the pupils' book. Attention is called to this fact, for it is important to recognize that no textbook should be slavishly followed. The general principles underlying a textbook presentation may be universally valid, but details of method should always remain subject to modification by individual teachers.

(*a*) A certain amount in the tissues, blood, and lungs is necessary for the normal functioning of the body. In cases where breathing has become shallow, for example, through carbon monoxide poisoning or through drowning, a mixture of carbon dioxide and oxygen is the best remedy; the carbon dioxide stimulates the respiratory centres and re-establishes deep breathing.

(*b*) It is used to improve the "taste" of drinks and to make bread and cakes rise.

(*c*) It is food for green plants and thus it is one of the sources of the energy-giving food we eat, and of the fuel we burn.

Though it is not desirable to reveal to children at this stage all the details in the above paragraphs, the usefulness of carbon dioxide should be stressed from the start. Another important fact to be taught is that carbon dioxide is the gas made when carbon burns. This will prepare the way for the study of starch formation and the oxidation of food.

Breathing need not be by any means a commonplace topic. A count reveals the number of breaths a pupil takes in a minute; a calculation and a little reflection raises the question why this incessant moving does not tire him. The air which he has for so long taken for granted is a great ocean as real as the Atlantic; he with hosts of other breathing creatures lives at the bottom. A great deal of junior-school nature knowledge can now be marshalled, and the breathing of birds, spiders, caterpillars, insects, worms, fish, and whales comes under rapid review. All these creatures have openings through which they breathe; some have noses, and we study with new interest the hygiene of nose-breathing. But living things include plants and trees, and we learn by simple experiments that they too must breathe. There is no room for the fallacy, once common in school science, that whereas animals inhale oxygen, plants inhale carbon dioxide. So far as we have discovered up to this stage, all living things breathe, and in so doing they increase the amount of carbon dioxide in the air. When our pupils look out on the world, they now see a picture of countless living things breathing—in the air, on the earth, in water and underground. We remind them how important clean air is for living things and we pass on to a study of feeding. This will reveal, *inter alia*, what becomes of the carbon dioxide made by breathing.

**Feeding.** (*E.G.S. I*, Chapter III, *Feeding*, pp. 21–48.)

SUMMARY

Six kinds of foodstuffs—Water, the best thirst quencher—Health-giving salts of the earth—Energy-giving foods: starch and sugar—Where do starch and sugar come from?—The wonders of plant growth—Another energy-giving food: fat—Body-building food: protein—Vitamins for healthy growth—What ought we to eat?

Energy should be a central theme in any course of general science. It can be introduced here without any elaborate explanation, for all the pupils know that they would not feel energetic if they did not partake of food. The close parallel between fuel and food can then be mentioned. But living things do not merely use energy; they also grow and repair themselves. Body-building and health-giving foods are needed in addition to energy-giving foods. Water is an obvious necessity.

In studying water, we may begin by considering " dried " foods. The meaning of evaporation and boiling having been taught, we pass naturally to the salts of the earth and to other mineral substances. These provide us with material for studying solubility in water, filtration, sediments, and crystallization. By burning away the vegetable matter from samples of food, the pupils learn what small quantities of salts food contains.

The study of starch and sugar as energy-giving foods leads us directly to the problem of plant growth. The pupils are surprised to see from experiments that both these foods contain carbon. They eliminate soil as a possible source of carbon, and by simple experiments they find that green plants growing in sunlight make starch if there is carbon dioxide in the air. First we learned that when plants are breathing they give out carbon dioxide; now we learn that when plants are feeding they take in carbon dioxide. A further experiment shows that water is also necessary. "A colourless gas and a colourless liquid are combined together by green leaves growing in sunlight, and the result is starch, a white solid." (*E.G.S. I*, pp. 40–41.)

The study of fat, another energy-giving food, should reveal the wide range of fats and oils in Nature, and their common origin—carbon dioxide in the air and water in the soil. Petroleum, though inedible, should be mentioned, for, though its origin is not definitely known, it is in all probability, like coal, a product of plant life. "How much we owe to plants and sunlight! Plants growing in our present sunlight provide us with starch, sugar, and fat to eat; they are the source of our bodily energy. Plants growing in sunlight thousands of years ago have left us a plentiful supply of coal and oil to burn; they are the source of the energy we get by means of engines." (*E.G.S. I*, pp. 43–44.)

Very little can be done with proteins, for the pupils will not study nitrogen until the Second Year. They can, however, be told that again we and the animals depend on plants, for plants alone can manufacture proteins, using starch, sugar, and salts, particularly nitrates.

The story of vitamins is a fascinating one and is especially valuable because it provides a clear example of the progress of modern science which children can appreciate.

The pupils are now in a position to discuss in a simple way the question of a well-balanced diet. The value of milk should be stressed and the desirability of avoiding monotony. "The safest general rule for diet is to take a good variety of plain food so that the body may take from it the supplies of the different kinds of material which it needs." (*E.G.S. I*, p. 48.) This brings us to the subject of digestion which is mentioned as a topic for the Second Year course, and we pass on to study how the energy we obtain from food is used to move ourselves and other things about.

**Moving.** (*E.G.S. I*, Chapter IV, *Moving*, pp. 49–73.)

SUMMARY

Why living things move—Men and machines—Muscles, the movers of living machinery—What makes things heavy?—How work is measured—A force which stops things sliding—How to lift heavy weights by small forces—Bone and steel—Why the see-saw balances—Why things topple over—The advantages of machines.

Moving has two important points of connexion with feeding. First, the necessity of searching for more food is one fundamental cause of their moving; second, the energy used by living things when they move is obtained from the foods they have eaten. This is the place to bring together a great deal of nature knowledge about the movements of plants and trees, and of the many young creatures which the pupils know are hatched from eggs.

A consideration of how we move our living machinery leads to the study of muscles, and pupils are interested to learn that the lean meat we eat is animal muscle. Fish, which have to move quickly in a denser medium than air, have for that reason a very high proportion of muscle. We now introduce the terms, force and work. We are able to move things (to do work) because we have energy at our disposal, the same is true of engines which move trains and cars. Thus we are gradually preparing for the introduction of heat and electricity as forms of energy.

We use a great deal of muscular energy in lifting things. We exert a force to make them rise, but what makes them fall? Falling has become such a commonplace event that children see no problem here. Time may be well spent in making clear that things do not move, not even downwards, unless some force is exerted. We take hold of a darning needle and pull it; we then thread it and pull it by the thread; we then pull it by moving a magnet a little distance away. A mysterious force is exerted across space; there is no holding and no thread. Similarly, when things move down towards the earth, some force must be pulling them; things behave as if they were connected to the centre of the earth by invisible threads which someone is pulling. Reference should here be made to Sir Isaac Newton (1642–1727). He noticed that, in order to keep a thing moving in a circle, it is necessary to exert a pull towards the centre. Pupils have often noticed this when swinging a bean-bag. The moon is whirling round the earth; it is not attached and yet it behaves like the bean-bag. It does not rush off into space, for the earth is pulling it. Newton was the first man to see that this pull is exactly the same pull as the earth exerts on an apple to make it fall. So we try to help children to appreciate the reality of the force of gravity.

We pause to notice some examples of whirling objects—milk in a cream separator, mud on a bicycle wheel, a bursting fly-wheel—all trivial in comparison with the whirling of the moon and planets, but subject to the same law. Things—moon, planets, milk, and mud—when once set in motion tend to move in a straight line; force is necessary to keep them moving round and round.[1]

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[1] This tendency to move away from the centre of rotation is popularly called "centrifugal force"; strictly speaking it is not force, any more than it is force which is stopping a book from starting to move across the table. It is the result of a property (called inertia) which is possessed by all matter.

Returning to the force of gravity acting on objects being lifted, we explain how work is measured in foot-pounds. The idea, though strange to children, is not difficult, and as we shall see later, it is of fundamental importance when studying the advantages and limitations of engines and machines.

Friction, a force which stops things sliding, enables us to adumbrate the idea that *heat is a form of energy*. It is extremely important for future work that this should be the first and most lasting idea of heat which our pupils get. Friction is too often neglected in "school" mechanics; in real mechanics it plays a very important part.

It is not necessary to spend a long time on elaborate experiments with levers. Qualitative experiments using a map-pole to tilt really heavy objects, are far more convincing than quantitative experiments with delicate apparatus. The pupils discover that the farther away from the fulcrum a force is applied, the greater is its effect; they are now ready to make many important applications. Handles are broken off saucepans, fixed mirrors are wrenched off dressing tables, because this simple rule is ignored. (The study of levers is interesting and useful to girls as well as to boys.) In the human forearm the muscular force can only be applied very near the fulcrum; the forearm is a poor machine for lifting heavy weights.

The law of moments is one of the few quantitative laws which senior-school pupils with simple apparatus can easily discover. It is well worth doing, for it refines a piece of knowledge about see-saws which both boys and girls have known qualitatively since they were very young.

Balancing suggests the idea of centre of gravity. It is waste of time to find the centre of gravity of pieces of cardboard; the most that need be done is to make clear the idea of weight acting through a point by balancing some common objects in different positions on the finger and discussing the approximate position of their centres of gravity. We

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are now able to discuss why things and babies topple over. Girls will then be more intelligently critical of the shapes of vases and boys more intelligently appreciative of the low centre of gravity of the latest type of motor-bus.

Returning to the "see-saw" lever,[1] we teach the meaning of the important term, mechanical advantage. Experiments are repeated to find if it is really true that this advantage can be obtained, as it were, for nothing. It is seen that the less the force you have to exert to move a heavy weight, the greater the distance you have to move the hand which applies the force. An appeal to common sense, with the aid of the pupils' previous knowledge of the measurement of work, settles the difficulty. The work done at one end of a "see-saw" lever cannot be more than the work we do at the other end: in practice it is less because of friction.

Returning to the "forearm" lever, we see that, although it lacks mechanical advantage, it has great advantages of convenience. It enables us to move our hands quickly through a long distance; by diminishing rather than amplifying the force exerted by muscles, it enables us to make very delicate movements. But "when it comes to moving heavy things about, we are by Nature rather handicapped. Thousands of years ago man's life was probably quite simple and he needed very little more machinery than that which Nature had given him. As he developed, he began to construct homes and to carry his food about from place to place. These needs obliged him to devise ways of doing heavy work which was beyond the power of his arms. As we have seen, the lever, an extension of his arms, was one of his first inventions. Primitive man's club, the canoe paddle, and the craftsman's hammer, are simple illustrations." (*E.G.S. I*, pp. 71–72.)

We should, however, be very helpless when moving unless we were guided by the news of the outside world which we get through our sense organs.

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[1] It is convenient to be able to refer to the three orders of levers by special names, but there is no great virtue in knowing (or not knowing) them as levers of the first, second, and third orders. For senior-school children, they may be called by more descriptive names, e.g. "see-saw" levers, "wheel-barrow" levers, "forearm" levers.

**Sensing.** (*E.G.S. I*, Chapter V, *Sensing*, pp. 74–114.)

### SUMMARY

How our brains get news from the outside world. *Seeing:* How light brings us news—What happens to light inside the eye?—How we are able to see moving pictures—Why we have two eyes—Why we cannot see in the dark—Why we see some things easily—The sky at night—Lights and shadows—Why we see ourselves in a mirror—Things are not always as we see them—How to use light to make pictures—How light pictures can be preserved. *Hearing:* How sound brings us news—How sound is made—How we hear sounds—How to make sounds louder—High and low sounds—Sounds we do not like to hear—Sounds which come back.

We begin by a rapid survey of nature knowledge, for the pupils probably know a good deal about the sensitivity of plants and animals, especially to light. Eyes come naturally into the discussion as specially sensitive parts of our bodies. This provides a good opportunity for giving children some idea of the wonderful structure of eyes, and for effectively revising the hygiene rules learnt in the junior school.

**Seeing.**

One of the most difficult ideas for children is that we see only because light enters our eyes. There is a tendency to revert to the primitive and child-like notion that eyes have some magic power; that when we see, some virtue goes forth from eyes to the objects which are in the light. In this connexion, it is a definite advantage to approach the subject as " seeing " rather than as " light ". Another helpful device is a simple comparison of eyes with cameras, leading inevitably to some consideration of moving and stereoscopic pictures. The usual experiments with pins should be excluded (both here and later when refraction is studied), for they tend to confuse rather than to clarify children's ideas about seeing and light.

A discussion of the question "Why we cannot see in the dark" should finally clinch this important matter. This discussion introduces also the important topic of reflection, not the special and more difficult case of reflection from mirrors, but the general idea that opaque things reflect light to our eyes. The difference between opaque and transparent things, between black and white, night and day, can now be discussed.

We learn that some things are really alight; they are emitting light. Other things are merely lit up by light which falls on them; they are reflecting light. This is made still clearer by a study of the sky at night, though we must remember that it is difficult for some children, even at the age of eleven, to realize that the moon and planets are lit up and are not in the real sense of the word alight.

It will be seen that our topic leads us naturally to astronomy. No course on seeing would be complete without some reference to the sky at night. The aim here should be to revive the interest which very young children spontaneously show in the heavenly bodies, and to help the pupils to get some realization of the majesty and wonder of a common sight. The immense distances of stars and nebulæ, their size, the time light from them takes to reach us, above all some contemplation of the sky at night—these are the obvious topics. An interest in stars is one of the results of science teaching which, perhaps above all others, may remain permanently with children who are poor in circumstances or even in intelligence.

Having learnt that everything we see on the earth and in the sky is either "alight" or "lit up", we notice the many intermediate shades between high lights and deep shadows We help pupils to realize that what they call a shadow is the end of a "mass of shade" in space. The same is true of a bright spot; it is the end of a beam or a flood of light.

The whole of space is filled with floods of light and " masses of shade ". We now return to astronomical space and consider briefly the occurrence of eclipses.

When, by discussion of simple observations, children have obtained a firm grasp of the importance of reflection in general, the special case of reflection from a plane mirror may be tackled. Beams of light can be reflected from mirrors and the paths made visible by smoke. It is clear that the angles made as light strikes and leaves the mirror are equal, and time can be saved by omitting detailed measurement and technical terms. Incidentally, the fact that light travels in straight lines will be noticed; there is no need to perform unconvincing experiments with cardboard and string.

The following difficult idea must be taught and reiterated on every suitable occasion: no matter where things may really be, they always *appear* to be in the direction from which their light enters our eyes. This idea is necessary both for appreciating the formation of images and for the understanding of refraction.

The " bent stick " experiment is a sure way of confusing beginners in the study of refraction. The best method is, if possible, to show a beam of light actually bent as it passes through a tank of water to which a little milk has been added. Failing that, the best alternative is the experiment showing a penny appear to rise in a bowl as water is carefully poured in. The penny does not move, nor does the observer; it must be the beam of light which comes from the penny to his eye. When the fact of refraction has been taught, striking experiments such as " bending a stick " may be done, but no laborious attempt should be made to " explain " the results.

A good test of the pupils' appreciation of the phenomenon of reflection is afforded by a discussion of how light makes pictures. There are two possible methods:

(i) the picture-book method in which the surface of the white paper is permanently changed;

(ii) the lantern method in which the white screen is temporarily changed.

In method (i) an even flood of light falls on the paper, but only certain parts are reflected. In method (ii), only the required light is thrown on the screen and this is reflected evenly.

We next inquire how it is possible to throw exactly the correct light on to a screen in order to make a picture. Either a lantern or a pin-hole camera makes a good starting-point. A pin-hole in a blind will produce a striking picture in a darkened room on a sunny day. If the hole is made slightly larger, the picture is blurred; if it is made large enough to admit a flood of light, the picture disappears; if then a convex lens is placed in the hole the picture reappears. The lens has bent the rays in towards each other again.

A note may be interpolated here on the use of diagrams to represent light. It is doubtful how far they increase senior-school pupils' appreciation of the subject; unless they are used sparingly by teachers and with discretion, pupils may develop the habit of using them merely as effective cloaks for ignorance. When a diagram is required to show the formation of an image, it is generally advisable to draw a pencil of rays from one point on the object;[1] arrows should always be inserted and pupils should frequently be required to describe in words what the diagram represents.

When studying lenses, no attempt need be made to establish the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$; this is outside the scope of senior-school science. A simple experiment can, however, usefully be done to determine the relation in general terms for an object (say, a candle) and its real image. It can be done, and if necessary, repeated many times in a few minutes so that pupils get a clear idea that the farther the object, the nearer and smaller is the image. This is a more valuable idea than that which many pupils get who "discover" and use the formula, and it is all that is required to enable them to grasp the principle involved in focusing. The experiment can be repeated with the limitation that both the candle and the screen are fixed; the lens must be moved as in a camera. If candle, screen, and lens are fixed as in the eye, what can be done? The pupils are now in a position to appreciate the wonderful mechanism of eye accommodation; some useful hygiene lessons can be taught and the use of spectacles simply explained.

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[1] Excellent diagrams of this kind are to be found in *Sound and Light for Schools*, F. Barraclough (Univ. Tut. Press).

Following the natural historical development of the subject, we next inquire how temporary pictures made by light can be preserved.

A study of the chemistry of photography is out of the question, but the pupils can be shown that some silver salts are sensitive to light; they can be told something of the story of early attempts at photography, and they can perform some simple experiments with modern films and printing-out paper.

The question of colour photography raises the problem, What is colour? This must be reserved for next year, and we break off to study hearing.

## Hearing.

Hearing is linked up with moving, for it is clear that nothing which is perfectly still can make a sound. The fact that things which vibrate slowly produce no sound suggests the need for quick vibrations. An experiment with an electric bell in an air-pump receiver shows the need for air as a sound carrier. After demonstrating that water, wood, and iron will also carry sounds, a simple explanation of wave-motion can be given. This will prepare the way for the difficult idea of ether waves which will be required when colour is studied.

The catching of sound waves is then discussed, reference being made to dogs and rabbits and to the interesting fact that we have lost the power of moving our ear trumpets.

A simple description of the human ear should then be given to bring out the following points:

(i) The importance of the eardrum.
(ii) The use of the wax.
(iii) The fact that the middle ear is open to the nose and throat.
(iv) The fact that, like the eye, the ear is connected to the brain by nerves.

If the junior-school hygiene instruction is then revised, it will be found to have acquired increased significance.

A violin and a tuning-fork are enough apparatus for the simple experiments necessary to show how to make sounds louder and how to make them high or low.

When the subject is treated as sound and not as hearing, it is often confined to a study of musical notes. There are, however, many sounds in modern life which we do not like to hear, and the study of noise and its prevention must be an important topic in any course on the science of living. The only other topic suggested is a study of echoes, how they are eliminated, and how they are used to amplify sounds in modern buildings.

**Book for Reference:**

*Elementary General Science*, Book I, A. G. Hughes and J. H. Panton (Blackie).

## CHAPTER III

# A Second-year Course

**Introduction.** (*E.G.S. II*, Chapter I, *The Science of Living*, pp. 1–5.)

In order to emphasize the fact that we are studying the science of living, we begin by taking a walk down a street, noticing the scientific facts about the life around us. Bearing in mind what the pupils have learnt in the First Year, it is interesting to look around on any common street scene and recapitulate the whole of the work done in the previous year. Space forbids a detailed description here, but the reader who has followed the previous chapter will appreciate the new significance which many common sights will now have for well-taught pupils. Everywhere people are breathing and increasing the amount of carbon dioxide in the air; they are moving—using the energy obtained from food eaten at recent meals; the shops are full of food, reminding us of air and water and soil and sunlight; the air is pulsating with sound waves; light is being reflected to eyes from innumerable opaque objects.

The pupils' intellectual interest in the world around has been deepened, but it has not been satisfied. They know something about the use of muscular energy for moving bar levers, but what makes the wheels of motor-cars go round? They know people are breathing, but why must they breathe? They know sound consists of waves in the air, but what is light? In this way, we give our pupils a bird's-eye view of the course for the Second Year, not by prematurely telling them the facts but by raising questions.

As in the previous chapter, we give below a detailed summary of the subject-matter which we recommend should be selected. Broadly speaking, we suggest pupils should learn in the Second Year that living creatures breathe in order to obtain oxygen for the oxidation of food; that water and carbon dioxide are the resulting oxides; that the feeding of green plants restores oxygen to the air; that the food of animals must be digested and then carried to all parts of the body by blood; that plants need nitrogen for making proteins, and this they get from soil in the form of nitrates; that all machinery consists of inclined planes and levers (including wheels); that the resulting heavy machinery necessitated the invention of engines so that heat, a form of energy released by oxidation, could be harnessed; that sunlight consists of ether waves of various lengths; and that the sun is the source of all the energy so far studied.

**Breathing.** (*E.G.S. II*, Chapter II, *Breathing*, pp. 6–23.)

SUMMARY

How and why do living things make carbon dioxide?—What happens to things when they burn?—The mystery of burning—Priestley's important discovery—Oxygen: the gas used when things burn—Oxides: the substances made when things burn—Oxides in the earth's crust—What happens when iron rusts?—Gas-fires and gas-stoves—What water is made of—Hydrogen: the water producer—Oxygen is necessary for burning and rusting—Why do we breathe?

We revise the facts that carbon dioxide is made when living things breathe and when carbon burns. Burning releases heat. We notice that our bodies are warm, and we ask whether it is possible that food is burnt inside them. With this brief introduction we begin a study of the mysteries of fire and burning. This is admittedly a digression, and it will be a long digression, from the topic of breathing. It is therefore necessary from time to time to remind pupils of the primary object of the work as stated above.

Burning has become somewhat commonplace by the age of twelve. We must try to revive the young child's attitude. Why is it that a stick will burn but a brick will not? When a stick burns, what really happens to it?

Here is an excellent opportunity of pursuing the historical development of the subject, and we begin with the " phlogiston " theory. That things lose " fire-stuff " or " phlogiston " when they burn is an explanation which seems as reasonable to children to-day as it did to the race in its scientific childhood. We therefore start with an experiment to find whether magnesium loses " fire-stuff " when it burns. We are not studying quantitative chemistry so the simpler method of counter-balancing is preferred to weighing; it is, moreover, much more convincing and vivid for children to receive ocular demonstration that their expectations are false, than to arrive doubtfully at the result at the end of a chain of reasoning and calculation. We now short-circuit the labours and arguments of the seventeenth-century chemists; this is necessary in the interests both of time and clarity.[1] It is easy to devise experiments to show that burning things " use up " a small part of the air and that the residue extinguishes flames.

The actual composition of air must be told to the pupils. The study of nitrogen is deferred until nitrates and proteins are dealt with; at present, pupils should merely be told that it is a very useful gas. In view of their use in modern life, the rarer inert gases, argon, neon, and helium are worth mentioning.

Priestley's experiment with mercuric oxide should be repeated, using a bunsen burner in place of a burning-glass. An attempt should be made to get pupils to visualize the meeting of Priestley and Lavoisier; it might even be dramatized. And the story ends with a description of Lavoisier's patient experiment in the following winter. The pupils thus follow the main route taken by the discoverers of oxygen, but they are spared the confusion which would result from an exploration of the by-paths.

While it is very desirable to show pupils various substances burning in jars of oxygen, no time need be wasted in teaching the details of the laboratory method of preparing it; our argument would lose nothing if the pupils never heard the words potassium chlorate and manganese dioxide. The best method is to collect a few jars of oxygen direct from an oxygen cylinder.

This is a convenient place to give a lesson on oxides in the earth's crust. Iron is such an important substance in modern life that children should have some simple notions of how it is recovered from ores. The reduction of lead oxide on charcoal is worth doing; it is for children a striking illustration of the recovery of a metal.

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[1] A very interesting account of the "phlogiston" theory is given in *Chemistry for Beginners*, E. J. Holmyard (Dent). It should be read by senior-school teachers, but not unloaded in all its completeness on to average pupils at the age of twelve.

Gas-fires and gas-stoves can next be studied. Carbon dioxide is met with again, and the simple experiment of putting an aluminium saucepan full of cold water on a lighted gas-stove for a few seconds reveals a fact which is a commonplace to housewives; beads of moisture are formed. The pupils will jump to the conclusion that they are drops of water and a word of caution will be necessary. The electrolysis of water should then be done. It is possible to fit up a home-made voltameter, but if this presents any difficulty, a voltameter should be bought. The expense is well justified, for the experiment is so striking and so important.

If the sequence suggested is followed, pupils meet hydrogen for the first time, as one of the components of water. This is putting the subject in its proper perspective, for hydrogen is primarily the " water producer "; its laboratory preparation using zinc and acid is in comparison at this stage a triviality.

We are now converging on a solution to our main question about food and breathing. We bring together our results:

(i) Coal-gas (or a candle, or sugar) burns; it uses oxygen, liberates heat, and produces carbon dioxide and water.

(ii) We breathe; the air breathed out is warm and it contains an increased amount of carbon dioxide and water.

There is only one missing piece of evidence; if food really combines with oxygen, where is the flame? But a flame is not always necessary, as we see by returning to experiments on the rusting of iron set up previously. We tell our pupils that their guess is correct; we breathe to obtain oxygen for the oxidation of food. How do food and oxygen get together in our bodies? The plan of the next section is inevitable; we must study digestion and blood circulation.

**Feeding.** (*E.G.S. II*, Chapter III, *Feeding*, pp. 24–51.)

SUMMARY

How food is changed in animals—How food is digested—How food is carried to all parts—What happens to blood in the lungs?—What happens to oxygen and food carried by the blood-stream?—Is the supply of oxygen in the air decreasing?—More wonderful facts about blood—The importance of green plants—Soil: a storehouse of plant food—How soil is made from rocks—Sediments which form rocks—Nitrogen: a very useful gas—How nitrogen from the air becomes part of the soil—What makes humus decay?—The need for artificial manure—How soil is supplied with water—Water sometimes flows up.

We begin by revising what we learned in the First Year about plant-food and sap, and by revising nature knowledge about the feeding of earthworms. The simple alimentary tube of an earthworm is contrasted with the complicated tract which we possess. Then the process of digestion is compared with that of dissolving mineral salts.

" In Book I, we learned that if we want to get clear solutions of substances quickly, we pound them up, mix them with a liquid, warm the mixture, and then, if necessary, separate the sediment. All this happens to food in the alimentary tract of an animal. The food is also changed in other ways before it is suitable to help animals to move and grow; the whole process is called digestion. It will be sufficient at present if you think of digestion as being the process by which food is made soluble." (*E.G.S. II*, p. 25.)

It is important to avoid all unnecessary details in describing digestion. The essentials are:

(i) *In the mouth:* the mastication of food and the action of alkaline saliva.

(ii) *In the stomach:* the churning of food and the action of acid juices.

(iii) *In the small intestine:* the action of alkaline juices and the slow passage of digested food through the tube walls to the outside.

The opportunity should obviously be taken of studying the effect of various substances on litmus. If desired, the ideas of neutralization and the formation of salts can be taught. The functions of ptyalin, rennin, and pepsin can be demonstrated by experiment.

A description of the lungs having been given, the pupils are ready to appreciate the double circulation of the blood. It collects food from outside the small intestine and oxygen from the lungs. Thus oxygen and food are carried together to muscles; when the sugar is oxidized, " some of the energy is set free in the form of heat, and is useful for keeping our bodies warm; some of the energy can, however, in a wonderful way, be used by us to make movements ". (*E.G.S. II*, p. 33.)

The function of the blood in collecting waste products of oxidation and of body-building leads to a study of excretion. The idea that the evaporation of sweat from the skin serves a very important purpose is mentioned, and the topic is reserved for the Third Year. Many hygiene lessons can now be effectively taught—the value of good teeth, of cleanliness both internal and external, of exercise and rest.

An experiment with a water-plant in sunlight suggests the explanation of our never-failing supply of oxygen. The pupils must be told that all green plants restore oxygen to the air in this way.

We then leave the energy-giving foods and consider how plants store up mineral salts, and how they make proteins. This entails a study of soil and is the natural place for an excursion into geology.

Our study of astronomy and of oxides in the earth's crust has prepared the way for a description of igneous rocks; our trivial experiments with sediments done last year help the pupils to appreciate the greatness and wonder of the deposition of sediments by Nature to form sedimentary rocks. Sandstone, slate, and marble are mentioned as common examples of metamorphic rocks. The collecting and naming of stones and rocks opens up a promising field of nature study which is not outside the scope of town children.[1]

Experiments with soil reveal its chief insoluble ingredients, and the pupils are helped by discussion and vivid description to appreciate their formation—" from nebula to garden ". In addition to the action of various inanimate forces on soil, the importance of the action of earthworms should be stressed. " The plough is one of the most ancient and most valuable of man's inventions, but long before he existed the land was, in fact, regularly ploughed, and still continues to be thus ploughed, by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world as have these lowly organized creatures."[2]

We now turn to the soluble part of the soil, paying special attention to nitrates. In so-called elementary chemistry nitrogen is often dismissed as being a mere diluent of oxygen; and while we are teaching this in school international conferences are being held to consider the world's supply of nitrates, so vital are they for the making of our food. We must desert elementary chemistry, and by means of simple experiments, the pupils must be introduced to the fact that soil contains bacteria. They can then be told of the action of nitrifying bacteria which cause humus to decay. Hitherto, these interesting greenless plants have been referred to as " germs "; it is important that the serious study of bacteria should begin with the action of *useful* kinds, for it will help to correct a false popular impression that all " germs " are harmful.

The need for artificial manure should be explained, and reference made to the Chilean nitrate deposits, to ammonium sulphate from the gas-works, and to modern discoveries of methods of making ammonia and nitric acid from the nitrogen in the air.

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[1] See, for example, the Preface to *Wonders of the Earth's Crust*, H. E. Taylor (Pitman).

[2] *The Formation of Vegetable Mould through the Action of Worms*, C. Darwin (Murray).

We are now in a position to link together the soluble and the insoluble parts of the soil. The latter are really water holders, and they thus ensure that soluble salts can be made available as food for plants. The drawing up and holding of water in the capillary spaces between soil particles opens up the fascinating topic of capillary attraction and surface tension. The theory of the subject is difficult, but its practical applications are so important and striking that they should not be neglected.[1]

We now leave the topic of body-building food until the difficult subject of growth is studied in the Third Year, and we return to the topic of energy and how it is used in moving.

**Moving.** (*E.G.S. II*, Chapter IV, *Moving*, pp. 52–98.)

SUMMARY

Climbing up hills and stairs—A useful machine: the inclined plane—Wedges: another kind of inclined plane —Climbing up spiral stairs—Screws: spiral inclined planes—Wheels: an important and wonderful invention —Mangles, bicycles, and mincing-machines: various ways of using wheels and axles—Egg-whisks and lawn-mowers: how one cogged wheel turns another—Bicycles: high and low gears—Carpet-sweepers and sewing-machines: how one plain wheel turns another—Clothes-racks: using wheels when moving things up and down—Electric-light pendants: another way of using wheels—Door-locks and bobbin-winders: how wheels can make things move to and fro—How things which move to and fro can turn wheels—Machinery of all kinds—Moving pictures made by fires—How does heat make winds?—How does heat make rivers?—How heat is used to move things—Boiling the kettle—How heat is measured—The heating value of foods and fuels—How heat reaches the water in the kettle—Good and bad conductors of heat—How heat makes water hot—Solids, liquids, and gases: how they expand and contract—How steam locomotives work—How steam turbines work—How motor vehicles work.

In the First Year we studied how man has increased the usefulness of his bodily machinery by inventing levers. We now notice the value of hills and stairs. This gives us an opportunity for explaining " power " as the " rate of doing work " and of describing Watt's experimental determination of " horse-power ". It is important to reserve the word " power " for this special meaning and to avoid using it, for example, when teaching levers, to designate force.

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[1] See *Soap Bubbles*, C. V. Boys (S.P.C.K.).

The mechanical advantage of an inclined plane can be demonstrated by pulling a heavily loaded toy truck steadily and slowly up a board; here again the use of a spring balance for measuring the force required is the simplest method. It is sometimes more convenient to push the inclined plane under the load; thus the wedge is introduced.

A consideration of spiral stairs is a good introduction to screws, for they are nothing more or less than spiral inclined planes. Some paper models of spiral inclines should be made and the term " pitch " taught. Large screws used for lifting are then easily understood. It is helpful to notice that the difference between a spiral incline and a screw is like the difference between an ordinary incline and a wedge. Screws are so useful in modern life that no boy or girl should leave school without an appreciation of their wonderful simplicity.

We now turn to wheels, a topic which is hardly ever accorded a place in textbooks or in school science commensurate with its great importance. We have only to imagine what life would be like to-day without wheels to realize that the wheel is one of the most important inventions man has ever made. It is also one of the most wonderful. Levers and inclined planes have been in the world as long as man himself; they are, for example, part of his own living machinery. But when man learned to make wheels, he had no natural wheel from which to copy.[1]

The titles given in the summary (p. 36) indicate clearly the wealth of interesting ideas about wheels which can be studied by experimenting with and observing common machines found in every home. The mangle and the bicycle illustrate two ways of using wheels and axles and remind us at once of the " wheelbarrow " lever and the " forearm " lever; in the mangle you amplify force, but in the bicycle speed is the first consideration. This is an excellent opportunity for revising the work of the First Year on levers and the various advantages of machines.

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[1] For further details of a fascinating subject, see *The Story of the Wheel*, G. M. Boumphrey (Black).

Toothed, or as we usually call them, cogged wheels are seldom studied in school, though modern life would be impossible without them. And what more fascinating subject is there for boys than gears? And for girls, mangling and egg-whisking may lose some of their monotony if they appreciate how the wheels go round. One wheel is used to turn another. The same idea applied to plain wheels is exemplified in carpet-sweepers and in the bobbin-winder on sewing-machines, and finally we notice the use of endless chains in bicycles and of friction belts in factories—altogether four ways in which one wheel is made to turn another.

The movable electric-light pendant gives us an illustration of fixed and movable pulleys. These terms often cause confusion to children owing to the fact that both types of pulley generally move round and round. If we do not shirk the question of friction, this point can be effectively dealt with. If possible, experiments with pulleys should be done with big weights and large apparatus so that friction cannot be ignored. The method of measuring efficiency can then be taught, ready for use again when heat engines are studied.

Another important topic is the conversion of rotary into reciprocatory motion and vice versa. The guides of an ordinary door lock, the double rack and pinion of a " French window " lock, the cam on the bobbin-winder of a sewing-machine, the eccentric used in steam engines—are all worth investigating. The reverse change by means of a crank should certainly be studied; it provides incidentally an excellent exercise in verbal expression.

The pupils are now in a position to take a more intelligent interest in machinery. They have a framework of knowledge which will help them to appreciate something of the working even of a complicated machine. They have four definite items to look for, viz.:

(i) The types of machine incorporated—bar lever, wheel or inclined plane.
(ii) The changing of motion—rotary to reciprocatory or vice versa; from one plane to another.
(iii) Special advantages exemplified; is speed or force amplified?
(iv) How and where friction is used or reduced.

It is worth while now turning back to consider our living machinery, and to compare it with the intricate machines made by man. We are apt to stand in awe and admiration before an artificial machine which imitates some human action; we often do not value our own machinery and that of skilled craftsmen as we should.

Having learnt a little about how the wheels go round, we return to the question: What makes the wheels go round? Previous work has supplied the answer—energy released by the oxidation of food in muscles or of fuel in engines. The pupils have been prepared in several ways to consider heat as a form of energy; they are ready to learn how heat can be made to do work. This is the way the subject should be approached, and all the other facts about heat, which are usually given pride of place, then fall into their proper and subordinate position. Once this all-important general principle is conceded, there are many ways in which the subject may be developed. One good method is to start straight away with a steam engine or a petrol engine and work back to elementary ideas. The method described here is less drastic.

We return to the subject of fire and notice the moving pictures made by a coal fire. We investigate the imitation pictures made in modern electric fires and find a fan moved by warm air. The formation of convection currents due to expansion of air by heat is dealt with and we pass on to consider how heat makes rivers. We note that the energy of falling water can be converted into electrical energy, but this subject is deferred until the Third Year.

Heat can be used to move things, not only things like air and water, but also such heavy things as trains. We watch (in imagination) an express train thundering along; heat is moving it. How is it done?

Experiments on boiling water show:

(i) Steam and boiling water have the same temperature.
(ii) Many volumes of steam are made from one volume of water.
(iii) Heat is required to change boiling water into steam.

By comparing the time it takes to bring some water to boiling-point with the time it then takes to change it into steam, we get a rough measure of " the latent heat of vaporization ", a term, however, to be avoided in senior schools.

Conduction is dealt with when considering how heat reaches the water in the boiler; the fact that water is a bad conductor is shown by heating it at the top, and the way it is heated by convection is demonstrated. We have now learnt that both air and water expand when heated, so we interpolate a short study of the expansion of solids, a topic which usually occupies more time than its relative importance warrants.

The pupils now have sufficient knowledge to enable them to understand the general principles of the working of reciprocating and turbine steam engines, and of internal-combustion engines.

It will be noticed that little has been said about thermometry and temperature. There are many more important topics than the making of thermometers. It is very doubtful if pupils in senior schools ought to spend time in making them or even in filling ready-made thermometer tubes. The fixed points can be dealt with incidentally—the boiling-point of water in connexion with steam engines as suggested above, the freezing-point in connexion with the freezing of ponds in the Third Year. It should be noted that in the manufacture of thermometers, the method of graduating is by comparison with standard instruments, and not, as many school courses seem to imply, by using melting ice and boiling water. The idea of temperature is almost as familiar to senior-school pupils as the idea of a chair; the difficulty arises when formal definition is attempted. It is suggested that such definition is quite unnecessary, and further, that no time should be spent in trying to arrive at a verbal formulation of the distinction between heat and temperature. Time is much better spent in developing and enriching the idea that heat is energy. The same " amount of heat " can be given to different weights of water, either by means of a bunsen burner, or better, by immersing a lighted electric lamp. The chief units used (B.Th.U. and calorie) can then be taught. Pupils will then be able to appreciate Joule's classic experiment to determine " the mechanical equivalent of heat ". This term need not be used, but all pupils should know that men of science have found out how much work 1 B.Th.U. of heat can do under ideal conditions; it is enough to lift a boy weighing 7 stones about 8 feet from the ground. The low efficiency of engines can then be discussed. The heating-value of foods and fuels is an important topic and provides an opportunity for explaining the meaning of " therm ".

Having expanded the pupils' knowledge of moving, both of the machinery used and of the way in which energy is harnessed, we return to the important topic of how these movements are guided.

**Sensing.** (*E.G.S. II*, Chapter V, *Sensing*, pp. 99–118.)

### SUMMARY.

How we get news from the outside world—Seeing things in colour—The mystery of rainbow colours—A puzzling question: what is light?—Light waves in the ether—Some experiments with colours—Some interesting questions about colours—Coloured lights and what they tell us—What everything is made of—Photographing things which are invisible—Valuable sunlight to which we are blind—Light: a form of energy—The sun: our most important source of energy—More mysteries in Book III.

The engine-driver needs signals which he can see, or in foggy weather, hear. At night coloured signals are convenient, and a reference to colour blindness helps to lift the subject out of the realm of the commonplace; there is something mysterious about colour.

A good starting-point is to make a list of where rainbow colours can be seen, a topic which should be studied in every junior school. From a consideration of this list we conclude that colours must actually be in sunlight all the time; we need some means to sort them out. A good sunlight spectrum should then, if possible, be arranged.

We are now confronted with a real difficulty. How can we give children any idea how it is that we see colours? The First-year work has prepared the way. First, by insisting on treating the subject as seeing and not light, the pupils are ready for the idea that we see colours because different messages reach our brain; the emphasis is not so much on, What is colour? as on, Why do we see colour? Second, our study of hearing high and low notes has prepared the way for pupils to guess that the different messages which cause us to see different colours may be the result of waves of various lengths. But since light travels from the sun through miles of airless space, the waves cannot be air waves. So we arrive at the hypothesis of the ether, and ether waves.

Experiments on mixing colours should be done, and the simple experiment of staring at red for half a minute and then looking at white, when a green spot will be seen. These experiments help children to grasp the very difficult idea that seeing colour is the result of messages reaching the brain. There are now many interesting problems worth discussing, for example:

*Discussions.*—(*a*) Look round the room at the various colours on the walls, in pictures, on books. Explain how it is you can see these colours.

(*b*) Why does grass look green? Which part of sunlight do you think plants need in order to make starch? Try to test your answer by growing plants, some under green glass, some under red glass.

(*c*) How are rainbows formed?

(*d*) Why is the sky blue? (*E.G.S. II*, p. 106.)

The coloured lights of fireworks provide a starting-point for a simple description of spectrum analysis; sodium and copper compounds are convenient ones to use in classroom experiments. Children will be interested to learn that a spectrum is as useful to a man of science who wants to identify a substance as a fingerprint is to a detective who wants to identify a criminal. A return should now be made to astronomy, and the pupils should be given some idea of how men of science determine the composition of the sun and stars.

A digression is permissible here to discuss the topic of elements, compounds, and mixtures; it will be the means of revising a good deal of work, for example, on starch, sugar, and oxides. It will also prepare the way for our study of protoplasm and growth in the Third Year.

In the First Year we learned that some air waves do not cause us to hear; their frequency is either too high or too low. We now teach the same idea in regard to ether waves. Recent developments in photography, both infra-red and ultra-violet, provide the necessary evidence of the existence of waves to which we are blind. This topic enables us to revise what was learnt in the First Year about photography, and it prepares the way for a reference to X-rays and wireless waves in the Third Year.

The difference between heat radiated from the sun and heat radiated from fires should be shown by experiments with glass, so that the pupils do not get the idea that all infra-red waves are the same length. Some modern work on ventilation suggests that it is the absence of the shorter infra-red waves which makes the heat from some fires "stuffy"; the longer infra-red waves do not stimulate the skin.

The importance of ultra-violet waves for health should be stressed, and several rules of hygiene about open-air life and open windows will acquire new significance.

We now return to the theme of energy. A red-hot poker can just be seen in a dark room; a white-hot poker can be seen plainly. Heat, a form of energy, can be changed into light. An experiment with a bright and a blackened tin containing water shows what becomes of light which, as we learned in the First Year, is absorbed by black things. It is changed into heat. So we arrive at the fact that the sun is our most important source of energy.

We can now understand a little better why growing plants need sunlight. They need energy to join together the elements in carbon dioxide and water to make starch, sugar, fat, and wood. This energy they obtain in the form of sunlight.

The sunlight energy used by plants is not lost. This is one of the amazing facts about energy; you can change it from one kind into another, but you cannot destroy it. The sunlight energy which plants use is in a mysterious way stored up in the starch and other substances which the plant makes. There it remains until it is released again by burning the substances.

When you see fires burning, you now know that the heat they are producing is energy which was at one time sunlight. When you see people and machines moving about, you know they are using energy which has also at some time come from the sun in the form of light. Green plants have caught this energy and stored it up for us in much the same way as energy is stored up in the spring of a clock after it has been wound up. Some sunlight energy has been buried in the earth for thousands of years in coal and oil; some has lain in shops for months in wheat and flour and potatoes. But in the end, just as the energy stored in the wound-up spring is released to do useful work in driving the clock-wheels, so the sunlight energy hidden away in fuel and food is released. In living creatures, the energy is set free by the oxidation of food in muscles; it can then be used to move living machinery. In man-made engines, the energy is set free in the form of heat by the burning of fuel in furnaces or cylinders; it can then be used to move artificial machinery. (*E.G.S. II*, p. 116.)

**Book for Reference:**

*Elementary General Science*, Book II, A. G. Hughes and J. H. Panton (Blackie).

## CHAPTER IV

# A Third-year Course

**Introduction.** (*E.G.S. III*, Chapter I, *The Science of Living*, pp. 1–6.)

There is perhaps no better way of revising previous work than by going out into a place where life and movement abound and trying to describe the surroundings as completely as possible. A busy street, especially if it contains trees or grass, is an ideal place. After two years' study of the science of living there is scarcely anything which is devoid of scientific interest. Start with such an unpromising thing as a dead leaf being blown about and consider some of the science lessons it suggests, e.g.:

(i) *Its present existence:* wind and convection currents; falling and the force of gravity; evaporation; colour; the sound of rustling.

(ii) *Its previous life:* breathing; colour; carbon assimilation and the storing of sunlight energy.

(iii) *Its future existence:* soil and bacteria; decay; nitrates; solution; water; capillary attraction.

Everything which can be observed in any common street scene is in some way related to work which has been suggested for the first two years. There are, however, still some important problems to be studied. For example, an airman passes overhead—how does he know how high he is? A shopman starts an electric fan working—why is ventilation necessary? how does electricity move things? A cat and kitten come into sight—how do living things grow?

It is not worth while suggesting in detail how a bird's-eye view of the Third Year work can be given. The teacher of science must be an opportunist; it is certain that five minutes' experience almost anywhere will suggest the important lines of investigation still to be pursued.

**Breathing.** (*E.G.S. III*, Chapter II, *Breathing*, pp. 7–36.)

SUMMARY

How lungs and bicycle pumps are emptied and filled—The wonderful movements we make when breathing—The importance of deep breathing—Why air always fills empty spaces—Various ways of using our ocean of compressed air—Breathing at high altitudes—Breathing at great depths—Eating, drinking, and breathing—Using our ocean of compressed air to lift liquids—How airmen know how high they are—Another use for pressure measurers—How atmospheric pressure is measured—The importance of fresh air—Three rules for good ventilation—How is your classroom ventilated?—Some difficulties of ventilation.

Although people use atmospheric pressure very frequently, they do not often recognize that they are doing so. This is because we have developed a habit of glibly " explaining " the effect of this pressure by the use of expressions such as " suck up ", " draw in ". The first difficulty therefore is to reveal to children that the act of " breathing in " requires any explanation.

A bicycle pump shows the problem more clearly; why does air rush into it in any direction? It is then worth while spending a little time getting the pupils mystified as to how air gets into our lungs. All we do is to make movements;

if we stop these breathing movements, we cease to breathe. This is the place to digress slightly and teach the hygiene of deep breathing.

Returning again to our main problem we show by experiment that air has weight and so arrive at the idea that we live in compressed air. The idea that air compressed in a closed space exerts a pressure is familiar; the difficulty is to get the pupils to see that air is, for all practical purposes, confined in the space around the earth just as air may be confined in an enclosed space. This gives a good opportunity for deepening their appreciation of the effect of gravity. The next difficulty is to get them to see that the air in a room exerts just the same pressure as the air outside at the same level. They must be led to realize that one part of the atmosphere is not shut off from another part; if, for example, we lessen the air space in the hall at assembly we do not compress the air more than usual—some of it escapes. The air outside is just as much or as little compressed as the air inside; it exerts the same pressure. There is no need to labour the point in the first lesson, for it is an idea which is required in all lessons dealing with atmospheric pressure, and it will become clear gradually as illustrations of its action are multiplied. Much of the difficulty which children experience in this connexion undoubtedly arises from the common method of talking in lessons on barometers about the weight of a column of mercury being balanced by the weight of a column of air. This type of explanation should be avoided, and in all lessons on atmospheric pressure the one idea that compressed air exerts a pressure should be stressed.

There are many interesting ways of helping children to appreciate the fact of atmospheric pressure, and these should precede any attempt at teaching how a barometer works Opening the modern type of lid, crushing a tin can, lifting weights by means of " suckers ", the Magdeburg hemispheres, are examples. The idea can be strengthened by vivid descrip tions of the difficulties of breathing at high altitudes, and in divers' compressed-air suits in deep water.

The idea of liquid pressure is thus introduced. It can be extended by a simple treatment of the topic of drinking. We proceed naturally from the use of atmospheric pressure in drinking to methods of using it to lift liquids which are not good to drink and to lift liquids in large quantities. The fountain-pen filler, the garden syringe, and the common pump are suitable illustrations. We thus try to give children a vivid idea of compressed air in action, pressing lids on to bottles, crushing tins, lifting liquids, and most important of all, forcing air into lungs.

When all this has been done, we may legitimately turn our thoughts to more precise methods of measuring atmospheric pressure. The simplest and most direct introduction is by means of an aneroid barometer. With an ordinary instrument, a difference in pressure can be seen between the cellar and the top floor of a three-storey building. The variations in pressure at one level then need explanation; this necessitates a revision of the over-simplified view of the atmosphere which has so far been given. But, except in special circumstances, a long excursion into meteorology is not recommended. For average pupils, it is enough if, on the theoretical side, they gain some idea of the complexity of the subject; for the most part, the work might well be kept on a practical rather than a theoretical plane. For example, it is interesting for pupils to watch the weather in relation to barometric readings taken in school, and also in relation to weather maps.

The figures round about 30 on the dial of the aneroid barometer now call for some explanation, and the usual experiments with a Torricellian tube must be performed. The pupils should by this time have a fairly clear idea of atmospheric pressure and the way it varies; their experiments on lifting liquids by drinking and by means of artificial apparatus will have prepared the way for the idea of pressure holding up liquids. This section of the work should therefore now take up very little time.

Having learnt how air is forced into lungs by atmospheric pressure, we turn our thoughts to the quality of the air breathed. The results of recent research suggest that it is necessary to avoid over-simplification when considering the meaning of fresh air. The amount of carbon dioxide is only one factor among many, for example, the movement of air and its relative humidity.

We now approach a subject which has obvious points of connexion with feeding, viz. the regulation of body temperature.

**Feeding.** (*E.G.S. III*, Chapter III, *Feeding*, pp. 37–71.)

SUMMARY

Keeping ourselves warm—Keeping ourselves cool—Good and bad drying days—Living in cold water—Measuring the amount of energy stored in foodstuffs—The growth and repair of living things—What living things are made of—A wonderful bit of protoplasm—More wonders of growth—Atoms and molecules—How life is passed on—Energy for eggs and seeds—Yeast: plants which are not green—More greenless plants: mushrooms—What makes food mouldy?—What makes food go bad?—Bacteria: the smallest living things in the world—What happens when you catch measles?—How to keep harmful bacteria at bay—The importance of clean food—Soap: a useful cleanser.

A discussion of the problem how to keep ourselves neither too warm nor too cold enables us effectively to revise a great deal of previous work. It also opens up a new problem: Why do we usually perspire more in hot weather than in cold? This involves teaching the important fact that heat is needed for evaporation; it suggests the value of some form of hygrometer, and it provides the occasion for some very necessary hygiene teaching.

Following our usual plan of studying the lower animals as well as human beings, we note the relatively high body temperature of birds and the comparatively low body temperature of fish. This is a suitable place to study the behaviour of water as it cools, for the fact that water begins to freeze at its surface is obviously of great importance in the science of living. Another important point is the use of frost in the formation of soil and as an aid to its cultivation.

The lower fixed point on thermometers is studied incidentally, and the difference between the centigrade and the Fahrenheit methods of graduation is noted. There is no need to take time from science lessons for exercises in converting readings from one scale to another.

It is now time to gather up the threads again, and after a glance at the calorific value of various foods, we turn our attention to body-building foods.

In order to give children some idea of the process of growth, it is necessary to introduce the idea of a cell. Ideally, the pupils should examine an amoeba under the microscope; in most schools at present this part of the work will have to be done by description and pictures. The simple method of reproduction by dividing into two is described and the pupils are now ready to appreciate to some extent the miracle of growth.

The growth of plant cells, involving as it does not only the formation of new protoplasm but also the strengthening of the cell walls as they expand, helps us to imagine molecules of cellulose as tiny " bricks " specially made for the purpose of building. Thus we arrive at the idea of the molecule of cellulose as being the smallest bit of cellulose which can possibly be made. But cellulose is composed of three elements, carbon, hydrogen, and oxygen. In this way, we approach towards the idea of atoms. An atom may be described as the smallest bit of an element which has ever been found to form part of a molecule.

Some teachers will prefer to refrain from any attempt at teaching about atoms and molecules, for the ideas are really outside the scope of science which can be understood in senior schools. The words are, however, now in such common use that it is difficult to justify their total exclusion from a science course which aims at completeness for the man in the street. The above outline is therefore given as a suggestion of a possible method of approach.

Chemical formulæ are similarly outside the scope of our course; most modern boys and girls have, however, heard of such formulæ as $H_2O$, and it is therefore desirable that they should learn in their science lessons what this means, viz. that in a molecule of water there are two atoms of hydrogen for every atom of oxygen. The use of formulæ should not, however, be encouraged. It would be very difficult to justify the use of chemical equations, and it is suggested that they ought definitely to be excluded from senior schools.

Returning again to the problem of growth and cell division, we must next teach that all living things grow from a single cell. Adhering to our general principle of starting all topics from human life, we would start by saying that we ourselves have grown from one cell—a cell made by two special cells of different kinds joining together. It is necessary to concentrate on the wonder aspect of this subject—the wonderful way in which cells are set aside for different kinds of work; the wonderful nature of living protoplasm, composed as it is of a few very common elements. Passing quickly but not hurriedly to other forms of life, we review junior-school nature lessons on growth from eggs and seeds. We tell our pupils how Aristotle thought that living things could develop from lifeless matter and how Pasteur finally established that it was not so. " Living protoplasm can only be made by living protoplasm. Life is passed on from one living thing to another." (*E.G.S. III*, p. 53.)

Senior-school pupils are now ready to observe with new interest the processes they watched in earlier years. In the junior school " perhaps you did not realize what miracles you were watching. Now that you have learnt something about cells and molecules and atoms, you will find it interesting to repeat some of the experiments you then did. As you watch the seeds germinate and the eggs hatch out, you will be able to think about what is really happening. The living cells in the seed or in the egg, under the influence of warmth and moisture, start feeding and getting bigger. They divide, and so the miracle of growth goes on." (*E.G.S. III*, p. 54.)

This is a subject which can be introduced in a lesson—a lesson which ought to be a very impressive one; it is not, however, a subject which can be finished in a lesson. The process of growth and reproduction must now be watched over a period of time in as great a variety of suitable examples as possible.

The wonderful way in which seeds keep alive even though they are buried is next described. They need a little energy, but they cannot obtain it by oxidation. They get it by a process we call fermentation.

Yeast can now be introduced as a plant which is able to obtain energy from sugar in this way, and the processes of oxidation and fermentation are compared:

*Oxidation:* Sugar and oxygen → carbon dioxide and water (energy is liberated).
*Fermentation:* Sugar → carbon dioxide and alcohol (a little energy is liberated).

Mushrooms, another example of greenless plants, should be studied; they illustrate a non-sexual method of passing life on and prepare the way for an understanding of the growth of moulds.

Food may go bad (i) on account of maggots, (ii) on account of moulds, and (iii) on account of bacteria. We now continue our study of bacteria, the tiniest of all greenless plants (see p. 35). Again we emphasize the usefulness of bacteria—for example, in producing the decay of humus in soil, and in helping herbivorous animals to digest cellulose. We then consider some harmful kinds, and such topics as Lister and antiseptics, Jenner and vaccination, are dealt with. We are now in a position to give a rational basis to a great deal of hortatory hygiene teaching which has throughout school life been given on the subject of cleanliness.

The topic of cleanliness enables us to revise work on friction, nose-breathing, solution, and it may appropriately end with a study of soap.

Breathing fresh clean air and feeding on fresh clean food are the key-notes of the work so far outlined in this chapter. Boys and girls of thirteen are ready to take an interest in physical fitness, and this interest can be used as a motive for much of the work suggested on breathing and feeding for the Third Year. Physical fitness connotes physical energy so that connexion with moving can also be maintained.

**Moving:** (*E.G.S. III*, Chapter IV, *Moving*, pp. 72–125.)

### SUMMARY

Making an electric bell ring—How electricity is switched on—Conductors and insulators—How an electric bell works—How magnets are made—Why terminals are marked – and + —How electricity moves things round and round—How a dynamo works—A.C. and D.C.—Electric radiators and lamps—Why we have fuse-boxes in houses—How electricity is measured—Electric sparks and lightning—How a sparking coil is made—A new kind of electric light—How X-rays are made—The wonders of radium—Storehouses of energy: food; springs; things high up; things on the move; fuels; electric cells—Moving on land, water, and in air—Floating and sinking—The meaning of density.

The one form of energy we have so far omitted is electrical energy. Pursuing our inquiry as to how energy is used to move things, we start with an electric bell, taking the production of an electric current for granted. The meaning of a circuit leads naturally to a study of conductors and insulators, and in studying how the bell works we learn about electro-magnets. Polarity of magnets, both permanent and electro-, having been investigated, an important experiment should be done leading to the discovery that when the wires connected to the two terminals of the battery are interchanged, the polarity of the electro-magnet is reversed. This suggests that there is a real difference between the terminals; that there is some reason for painting one red and the other blue. The pupils must be told that the difference (called a difference in potential) sets a current of electricity moving in the wire joining the terminals. If the analogy of water flowing in pipes be used, care must be taken that the pupils do not get wrong ideas; analogies are always dangerous and especially for children. The fact that P.D. is measured in volts by a voltmeter must be told and, if possible, a voltmeter should be used to show how the voltage of a current is increased when cells are joined in series to form a battery. Voltage is now such a common term that it should not be omitted.

The electric motor can now be investigated. The best method is probably to examine a simple toy model, remembering that all the essential facts have already been taught separately. These essentials are: (i) that the movement is due to the forces of attraction and repulsion between two magnets; (ii) that the motion is made continuous by reversing the polarity of the revolving magnet each half-turn; and (iii) that the rotary motion is possible because the circuit is made by the contact of " brushes " and not by wires actually joined up.

The historical development of the subject may now profitably be followed. Faraday argued that if a current of electricity can produce magnetism, magnetism ought to produce a current of electricity. It was seven years before he succeeded, apparently because he omitted one important idea from the argument, viz. the idea of moving. It is moving electricity (i.e. a current) which produces magnetism; it is a moving magnet which produces a current of electricity. If time permits, it is interesting to lead up to this problem in discussion and then leave pupils a week to think out possible experiments. In any case, Faraday's experiment of moving a magnet in a coil must be done. Some boys' schools will be able to make a galvanometer sensitive enough for the purpose; failing that, the purchase of a galvanometer for this experiment alone is well worth while. Finally, a toy dynamo should be examined and used to light a small lamp.

A.C. and D.C. are terms now in common use and this topic might be included. Faraday's experiment with an iron ring should then be done to explain the principle of the transformer.

A digression is legitimate to explain why we have fuse-boxes in houses. A simple study of resistance can be made, but a quantitative study of Ohm's Law is unnecessary. The most that need be done is to show that the strength of a current depends both on resistance and voltage. This can be done by dimming the light of a lamp, and for the experiment an electric torch lamp, two batteries, and a long piece of iron wire such as florists use, are sufficient apparatus.

The measurement of electrical energy is difficult. It should be kept on the practical plane, working from the wattage of common electrical apparatus. A unit (1 B.O.T.U.) is a kilowatt-hour, i.e. the energy used, say, by ten 100-watt lamps burning for an hour. If pupils, knowing the wattage, can calculate the cost of the current required for running electrical apparatus, nothing more need be done.

Electric sparks always fascinate children and they are, moreover, important in several ways. This is a suitable place to refer to frictional electricity. It has some important applications in modern life, but it is not a topic which needs elaborate treatment. Many children have played with shocking coils; an examination of their construction provides a useful revision of the principles used in the electric bell and transformer.

Neon lamps provide a good introduction to "vacuum" tubes, a topic which is becoming more important every day. The pupils should be told about modern developments in electric lighting, for it is probable that by the time they are grown-up, the whole business will have been revolutionized. Although the subjects do not lend themselves to experimental work in school, the pupils should also be told something about X-rays and radium. This involves teaching about electrons.

If, as we have said, the idea of atoms is really beyond the scope of senior-school pupils, what shall be said of electrons? It is difficult to justify their exclusion, for X-rays, radium, and "atom-splitting" are important and popular subjects to-day. There is a second reason for introducing the idea of electrons; it may help children to form a less erroneous idea of what an electric current is than the one usually held. We can teach them that the electrons are in the copper wire all the time, and that when it is joined to terminals at different potentials, a special force called electro-motive force sets them in motion. This is at least not so misleading as the idea of an electric cell being a reservoir filled with a mysterious "juice" which it sends out into the wires. In this connexion, it is important when teaching about electricity to refrain from talking about "making" or "producing" electricity. A dynamo or an electric cell does not make electricity; it sets electricity in motion. In other words, mechanical or chemical energy is changed into electrical energy. It should be noted that it is easier to make this idea clear if we approach the subject through the topic Moving than if we approach it in a conventional academic way.

If we do talk to children about atoms and electrons, we must realize clearly that when so doing we have stepped outside the bounds of children's science. They are no longer studying science; they are hearing about the results of science which have been determined by methods they cannot understand. This may be justifiable if only on the ground that it helps them to realize how little they know. If it is done in this spirit and with due warnings, teachers may well attempt to open out children's minds by talking occasionally for a few minutes on such subjects as modern theories of matter. If this kind of work is done, the pupils should not be required to write essays on it as if it were knowledge they were capable of assimilating; they should be left to wonder about it.

It is time to return to safer ground. The atom may be a storehouse of energy, but, except in radio-active substances, the energy is securely locked up. We now revise the storehouses of energy we can unlock. They are: (*a*) food, (*b*) springs (elastic), (*c*) things high up, (*d*) things on the move, (*e*) fuels, (*f*) electric cells.

This arrangement gives us an opportunity of teaching a little about elasticity and it has the special advantage of emphasizing how, in one respect, electric cells resemble fires. In both, chemical changes are taking place and energy is being released. The fact that oxidation is not the only chemical change accompanied by the liberation of heat is demonstrated, and then the question is raised whether energy in the form of electricity is ever released by a chemical change. A simple cell is then set up and various forms of the Leclanché cell investigated. It is not necessary to teach the details of the chemical changes which take place, and of course all theory of cell action is omitted. The general principle is important, viz. that the chemical changes taking place are accompanied by a release of energy:

| *Chemical change* | *Energy released* |
|---|---|
| In fire | Heat (mainly) |
| In electric cell | Electricity (mainly) |

In the "accumulator" type of cell, which should certainly be investigated, the principle is still the same. The charging of the cell is simply a method of renewing, by means of an electric current, the appropriate chemicals required in the cell.

We now look out on the world again and see energy released from these storehouses being used to move things—on land and water and in the air. There are still two outstanding problems: How do birds and aeroplanes fly? How do balloons and ships float?

The second problem suggests what is probably the most useful approach to the Principle of Archimedes. It is simpler and more purposeful to approach it by a study of floating rather than of sinking. Spring balances and toy ships are suitable apparatus for experimental work. A discussion of the Plimsoll line leads to the problem of sinking which is again best investigated by large-scale experiments—heavy weights in buckets of water. The meaning of density, adumbrated in several previous topics, is now made clear; there will not usually be time for the accurate determination of densities, nor is such work as important in senior schools as most of the topics suggested in this course.

Before passing on to consider further how movements are guided by sensing, it is worth while summarizing the various changes in the forms of energy which have been studied (see p. 59).

**Sensing.** (*E.G.S. III*, Chapter V, *Sensing*, pp. 126–132).

SUMMARY

How we get news from the outside world—How we get news by smelling, tasting, and touching—Our wonderful headquarters.

The fact that smelling is caused by inhaling something in the air can be demonstrated by experiment, and some interesting experiments can also be done on tasting.

The various ways of sensing may be summarized:

(i) Air waves striking our eardrums (sound).

(ii) Ether waves striking our retinas (light).

(iii) Ether waves striking our skin (heat).

(iv) Tiny particles touching special cells inside the nose (smell).

(v) Solutions touching special cells on the tongue (taste).

(vi) Anything touching our skin (pressure, roughness, temperature, pain).

After noticing that we get news, not only from the outside

### CHANGES IN THE FORM OF ENERGY
(From *E.G.S. III*, p. 125)

| *Energy* | *Changed by means of* | *Energy* |
|---|---|---|
| 1. Sunlight | Green plants | Chemical energy in food and fuel |
| | Evaporation of water | Energy of falling water |
| | Expansion of air | Energy of wind |
| 2. Chemical | Oxidation in muscles | Muscular energy and heat |
| | Oxidation in engines | Heat |
| | Various other chemical changes | Heat |
| | Chemical changes in electric cells | Electrical energy and heat |
| 3. Muscular | Friction | Heat and sound |
| | Machines and elastic substances | Mechanical energy, heat, and sound |
| 4. Heat | Engines | Mechanical energy and sound |
| | Lamps | Light |
| 5. Mechanical | Friction | Heat and sound |
| | Dynamos | Electrical energy, heat, and sound |
| 6. Electrical | Electric bells | Mechanical energy, heat, and sound |
| | Electric lamps and heaters | Heat and light |
| | Electric motors | Mechanical energy, heat, and sound |

world but also from the inside, from our own living machinery, we conclude the section with a simple study of our wonderful nervous system.

This brings us very near to the subject of thinking. Though it will be generally agreed that psychology is outside the scope of science in senior schools, this does not mean that nothing should be done to interest children in the wonderful ability they all possess—the ability to think and reason. This subject is one which, on the purely practical plane, should permeate every course of science. It will be referred to in more detail in Chapter X.

**Book for Reference:**

*Elementary General Science*, Book III, A. G. Hughes and J. H. Panton (Blackie).

## CHAPTER V

# Taking Stock

When teaching science by topics it is necessary to take stock occasionally in order to determine the science content of the course, that is in order to see how much science we are really attempting to teach. Stock-taking is also necessary in order to examine whether we are following the most suitable sequence.

### The Science Content of a Course of Topics.

The most convenient way of taking stock of the science content is to set out, under the conventional headings of branches of science, the titles of all the scientific phenomena dealt with in a course. Such an analysis is obviously for the information of teachers; it cannot be in any sense a syllabus of science for children. A mixture of the branches of science, such as the following analysis contains, no more warrants the title "General Science" or "The Science of Living" than a mixture of oxygen and hydrogen warrants the name "Water". The elements analysed out must be combined again into some kind of coherent whole, such as the one suggested in previous chapters; this is, moreover, necessary if they are to be assimilated by average children in three years.

Two most important subjects in senior schools are those usually referred to as hygiene and domestic science. They are not, strictly speaking, science; they are rather the applications of science to two important arts—the art of healthy living and the closely allied art of running a home. But, as we shall emphasize in the next chapter, the best way of approaching the facts of science is generally through their practical applications. Hygiene and domestic science should therefore have a prominent place in a senior-school science course, and for that reason they are included in the following analysis.

## ANALYSIS OF A SCIENCE COURSE

(In the course outlined in previous chapters, some items are incidentally adumbrated in early stages before they receive fuller treatment, and some are incidentally revised in later stages after this fuller treatment has been given. This explains why some items occur more than once in the following analysis.)

### YEAR I

**Astronomy**

(*Feeding.*) Sun, the source of light.

(*Moving.*) Movements of moon and planets round sun.

(*Sensing.*) The sky at night—day and night—eclipses.

**Biology**

(*Breathing.*) Rates of breathing—hibernation—respiration in animals (mammals, fish, amphibia, birds, insects, worms) —respiration in plants—bacteria.

(*Feeding.*) Pulse beats—nutrition (human beings)—excretion—nutrition (plants)—germination and growth—carbon assimilation—transpiration.

(*Moving.*) How plants and animals move to get food—muscles—nerves—vertebrates and invertebrates—survival value of quick-moving bodily levers.

(*Sensing.*) Sensitivity of plants and animals to light—construction of eye—persistence of images—binocular vision—construction of ear.

### Chemistry

(*Breathing.*) Lime-water test for carbon dioxide—preparation and properties of carbon dioxide—solubility of air in water.

(*Feeding.*) Salts—solution—crystallization—filtration—composition of foodstuffs—starch—sugar—fats and oils—carbon—proteins—vitamins—chemical change.

(*Moving.*) Composition of bone.

(*Sensing.*) Effect of light on silver salts (photography).

### Geology

(*Feeding.*) Soil.

### Physics

(*Breathing.*) Wind—atmospheric pressure—condensation.

(*Feeding.*) Energy and work—evaporation—melting.

(*Moving.*) Muscular energy—heat energy—force of gravity—measurement of work—friction—levers—wheels—law of moments—centre of gravity—mechanical advantage.

(*Sensing.*) Light, its reflection and absorption—shadows—mirrors—refraction—formation of images by means of pinholes and lenses—focusing—colour—sound, its transmission, formation, intensity, quality, pitch, reflection.

### Applications to Hygiene and Domestic Arts

(*Breathing.*) Carbon dioxide in food and cookery—nose-breathing—fresh-air baths—cleanliness of atmosphere (dust and smoke).

(*Feeding.*) Diet and health—water-supply—sunlight and health—vitamins.

(*Moving.*) Muscular exercise—dangers of strain—economy of energy in household work—cleaning by friction—prevention of accidents (centre of gravity and law of moments).

(*Sensing.*) Care of eyes—correction of defective sight—lighting of rooms—polishing—care of ears, nose, and throat—reducing noise.

## YEAR II

### Astronomy

(*Breathing.*) Formation of earth (oxides in the earth's crust).

(*Feeding.*) Formation of earth (rocks).

(*Moving.*) Sun, the source of energy.

(*Sensing.*) Composition of sun and stars (spectrum analysis)—sun, the source of energy.

### Biology

(*Breathing.*) Oxidation of food.

(*Feeding.*) Digestion—circulation of blood—lungs—oxidation of food—excretion—skin—plant nutrition—carbon assimilation—formation of proteins—nitrifying bacteria—decay of humus—earthworms and soil.

(*Moving.*) The heating-value of foods.

(*Sensing.*) Colour-blindness—retinal fatigue—infra-red and ultra-violet waves, effect on skin.

### Chemistry

(*Breathing.*) Composition of air—oxidation—preparation and properties of oxygen—recovery of metals from ores—preparation and properties of coal-gas—composition of water—preparation and properties of hydrogen.

(*Feeding.*) Solution—action of enzymes—acids and alkalis—litmus as an indicator—neutralization and salts—oxygen and hæmoglobin—oxidation of food—soil—nitrogen—nitrates—artificial manures.

(*Sensing.*) Spectrum analysis—elements, compounds and mixtures.

**Geology**

(*Breathing.*) Oxides in the earth's crust—coal.

(*Feeding.*) How soil is made from rocks—igneous, sedimentary, and metamorphic rocks.

**Physics**

(*Feeding.*) The heart as a pump—freezing of water (in soil)—capillary attraction and surface tension.

(*Moving.*) Horse-power—inclined planes—wedges—screws—wheels—wheel and axle—toothed wheels—pulleys—efficiency of machines—converting reciprocatory into rotary motion and vice-versa—convection in air and water—measurement of heat—latent heat of vaporization—Joule's mechanical equivalent of heat—heating value of fuels—conduction of heat—expansion and contraction caused by heat—steam engines (reciprocatory and turbine)—internal-combustion engines—efficiency of engines.

(*Sensing.*) Colour—infra-red and ultra-violet waves—sun, a source of energy.

## Applications to Hygiene and Domestic Arts

(*Breathing.*) Need of oxygen for breathing—lighting and controlling fires—preventing rust—uses of coal-gas—preventing explosions—dangers of carbon monoxide poisoning—dangers of inflammable materials.

(*Feeding.*) Cleanliness—exercise and rest—value of good blood circulation—skin as an organ of excretion—strengthening of muscles—digestion—care and use of teeth—use of capillary attraction in the home.

(*Moving.*) Avoidance of strain—value of labour-saving machines—uses for screws and nails—uses of wheels in household machinery—fire as an aid to ventilation—boiling the kettle—heating value of foods and fuels—therms—good and bad conductors of heat in the home—clothes—expansion and contraction by heat in the home—use of hot gases in cookery—hot-water systems—airing cupboards.

(*Sensing.*) Matching colours by artificial light—sunlight and health.

## YEAR III

### Biology

(*Breathing.*) Mechanism of breathing (mammals, birds, insects)—difficulties of breathing at high and low pressures.

(*Feeding.*) Regulation of body temperature—perspiration—protoplasm—reproduction—germination and growth—cell structure—fungi (yeast, mushrooms, moulds)—bacteria.

(*Sensing.*) Smelling—tasting—touching—nervous system.

### Chemistry

(*Breathing.*) Composition of fresh air.

(*Feeding.*) Protoplasm—cellulose—atoms and molecules—fermentation — antiseptics — soap — hard and soft water — solution.

(*Moving.*) Chemical change (electric cells).

(*Sensing.*) Solution (taste).

### Physics

(*Breathing.*) Atmospheric pressure—density—water pressure—pumps—barometers—weather forecasts—ventilation.

(*Feeding.*) Ventilation—evaporation—relative humidity—freezing of water.

(*Moving.*) Electricity—conductors and insulators—electro-magnets—magnetism—potential difference—electric motors—dynamos—measurement of electricity—electric heating and lighting — resistance — electric sparks — static electricity — vacuum tubes — X-rays — radium — matter and electricity — Principle of Archimedes—density.

(*Sensing.*) Radiation (heat).

### Applications to Hygiene and Domestic Arts

(*Breathing.*) Importance of deep breathing—life-saving—using atmospheric pressure to keep lids on tins—rules for good ventilation—sweeping and dusting.

(*Feeding.*) Diets for hot and cold weather—suitable clothes—changing clothes—dangers of draughts, dry air, moist air, damp clothes—preventing pipes from freezing—heating value of foodstuffs—bread-making—uses and abuses of alcohol—fermentation of food—moulds on food—eggs and larvæ on food—bacteria and cleanliness—spitting and sneezing—disinfecting—refrigeration—pasteurization—sterilization—preserving—washing—methods of cleaning.

(*Moving.*) Keeping electric bell in order—avoiding electric shocks—voltage of electrical apparatus—how to avoid short circuits—how to repair a broken fuse—care of electrical apparatus—danger of electric sparks in dry cleaning—value of X-rays and radium.

(*Sensing.*) Value of smelling, tasting and feeling—pain, a danger signal—anæsthetics—a healthy mind.

## Reviewing the Science Content of a Course.

Having taken stock of a course of science topics, the next step is to examine the list to see if any items can be deleted. Then the list of items under each heading might be compared with those given in a comprehensive textbook on the particular branch of science (see book list on pp. 69-70). Although this should be done in order to find whether any indispensable item has been omitted, care must be taken to resist the temptation of overloading the course for the sake of completeness in every branch. We must remember that we are not setting out to teach astronomy, biology, chemistry, geology, or physics; our aim is to teach the science of living.

Coming down for a moment to stern practical necessities, no senior-school science course can be considered satisfactory unless it introduces all the science necessary for teaching the "Health Lessons for Older Children" outlined on pp. 20–22 of the *Handbook of Suggestions on Health Education*;[1] this is the irreducible minimum. If a course under review appears too long, this criterion at least gives some guidance as to which items cannot be excluded.

In considering the science content of a course, it is, however, necessary to remember that science is more than hygiene. Scientific knowledge about bacteria may help to convince a young person that the rule about washing before meals is not merely a silly fad; knowledge about the heat required to evaporate water may help a youth to remember that it is foolish to sit about in damp clothes. These are good practical values to be derived from science teaching, but they are not by any means the sole or even the primary justification for lessons on bacteria and evaporation. These lessons, in so far as they increase the pupil's interest in the world around him, are well worth while, apart from their contribution to hygiene. To increase intellectual interest is the fundamental reason for teaching science. Herein lies the justification for including lessons which may have very little direct utilitarian value in senior schools, for example, lessons on steam and petrol engines, on electric motors and dynamos, on stars and nebulæ. Textbooks on domestic science and hygiene and on the various branches of science are useful checks for stock-taking purposes, but the deciding factor when considering the suitability of any item of science for a senior-school course must always be the ability and interests of the pupils being taught.

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[1] Board of Education, H.M.S.O.

## Suggestions on Sequence.

Sequence in a science course is influenced by so many local factors that it would be useless to make detailed suggestions. For example, in order to arrange for experiments with growing plants, a school beginning its science course in September might find it necessary to adopt a different sequence from another school beginning its course in April. There is, however, one important general principle which can be usefully discussed and illustrated.

In science, as in other subjects, it is desirable to teach difficult ideas as late as possible in the course; we should continually be on our guard lest we teach prematurely, with the expenditure of much energy, ideas which a year or two later would come more easily and naturally. For example, we suggest leaving the difficult subject of atmospheric and water pressure until the Third Year. This does not mean that no reference should be made to this subject previously. On the contrary, it is a good plan to adumbrate difficult ideas on any suitable occasion, and also to revise them frequently in fresh natural settings. This is inevitable if science is approached, as we recommend, by the study of topics, that is by the study of unanalysed natural wholes. Using this method, the same item of science will crop up on many occasions, and the important point to decide is on which of these occasions it should receive its main and detailed treatment.

Since the subject of pressure is difficult, we suggest its main treatment should be deferred until the Third Year, when it crops up in connexion with the mechanism of breathing. But it will be mentioned in the First Year in connexion with the height of the atmosphere, and again in the Second Year in connexion with steam engines and internal-combustion engines, and when teaching about sedimentary rocks. The geography teacher, too, may need to refer to the subject, though it is probable that, for average children, a great deal of scientific geography should also be deferred longer than is now customary.

In the study of energy, an important subject which should permeate every science course, the following sequence is suggested:

*First year:* energy used by muscles for moving (at this stage its existence must be taken for granted; it is then the most easily understood example of energy for children)—simple levers worked by muscular energy—conversion of mechanical energy into heat energy by friction—storing of sunlight energy by green plants.

*Second year:* ideas of heat and muscular energy deepened in connexion with oxidation and heat engines—conversion of sunlight energy into chemical energy, of chemical energy into muscular energy and heat, of heat into mechanical energy.

*Third year:* conversion of mechanical and chemical energy into electrical energy by dynamos and electric cell respectively

—conversion of electrical into mechanical energy by electric bell or motor—conversion of electrical energy into chemical energy in electro-plating.

The importance of sequence is another argument for teaching science in an organized course. This does not, however, mean that a prearranged sequence should never be broken. Every year there are special occasions of scientific interest—centenary celebrations, the publication of new and striking discoveries, the hatching of sticklebacks in a school aquarium, the occurrence of rainbows, earthquakes, hurricanes, fogs, snowstorms, eclipses, and the like—and the wise teacher will often seize these favourable opportunities, sometimes for a five-minute talk, occasionally for a red-letter lesson, outside the ordered sequence of his course.

The question of sequence is a difficult and complicated one, and is, of course, bound up with the nature study done in junior schools. Speaking generally, the principle to be followed is that of approaching scientific phenomena first of all in their natural setting, observing them and getting familiar with them, but not trying at first to detach and isolate them in a laboratory setting. Much of this preliminary work can be done in junior schools so that many scientific phenomena can be studied in some detail in the First Year of a senior-school course. Some phenomena, such as pressure and electricity, are, however, so difficult that it is desirable to continue studying them on the observational and descriptive plane beyond the junior-school age.

**Books for Reference.**—The Teachers' Reference Library should contain at least one comprehensive book on each of the subjects mentioned below. The following list is given as a suggestion of a suitable nucleus, but it will be realized that it is only one out of many possible selections which might be made from a very extensive literature:

ASTRONOMY.—*Astronomy of To-day*, C. G. Dolmage (Seeley).

BIOLOGY.—*Biology and Human Life*, B. C. Gruenberg (Ginn). *Elementary Biology*, M. E. Phillips and L. E. Cox (University of London Press).

CHEMISTRY.—*Everyday Chemistry*, J. R. Partington (Macmillan).

DOMESTIC SCIENCE.—*Everyday Domestic Science*, I. C. Joslin and P. M. Taylor (Macmillan).

GENERAL SCIENCE.—*The Science of Everyday Life*, Van Buskirk and Smith (Constable). *General Elementary Science.* W. Willings (Blackie).

GEOLOGY.—*Geology of To-day*, J. W. Gregory (Seeley).

HISTORY OF SCIENCE.—*The Master Thinkers*, R. J. Harvey-Gibson (Nelson). *Master Minds of Modern Science*, Bridges and Tiltman (Harrap).

PHYSICS.—*Everyday Physics*, H. E. Hadley (Macmillan).

PHYSIOLOGY AND HYGIENE. — *Readable Physiology and Hygiene*, J. A. Campbell (Bell). *Handbook of Suggestions on Health Education*, Board of Education (H.M.S.O.).

## CHAPTER VI

# The Approach to Science

In considering the question of "approach" in science teaching there are two distinct problems. First, there is the problem of the approach to the subject as a whole; second, to particular items in the course.

### The Biological Approach to Science.

For the subject as a whole we have already suggested a biological approach as being the most appropriate. This does not mean that science teachers must become specialists in biology; it does mean, however, that they must become, like little children, biologically-minded (see pp. 5-7). This will necessitate for many teachers a completely new orientation of science in school. In order to make this clear let us consider a few concrete illustrations of the effect of this new orientation.

To a teacher who does not think biologically, heat is often approached as that which is obtained from a bunsen burner; its uses, as illustrated in science lessons, are chiefly to make solids expand and to melt them. To a biologically-minded teacher, heat is approached as that which is obtained when we rub rough things together; it is primarily a form of energy. Heat energy, released from food, keeps us warm; released from fuels of various kinds, it is used to eke out our puny muscular energy and our small supply of bodily heat; it is capable of moving trains and ships and cars in the service of mankind.

To a chemist, soap is a salt of a fatty acid; to a teacher of science who has learnt to think biologically it is a substance which is very useful for emulsifying fat and so for removing dirt from the human skin. It is one of the means of ensuring that we eat food free from harmful bacteria; it is a means of counteracting the bad influence of a polluted atmosphere and of removing bad-smelling waste products. It is thus indirectly a means of helping to ensure that we are healthy and full of energy.

A person who is biologically-minded has a different outlook on the world from one who sees it merely in terms of mechanics, or physics, or chemistry. To take a simple example, everywhere he looks, he sees how man has utilized both organic and inorganic products in the making of modern commodities and appliances. A motor-car consists of glass and metals from the earth's crust, of leather and rubber from animals and trees: the safety glass, consisting of a layer of celluloid between layers of glass, is another excellent illustration; the walls of plant cells which were once alive are now sandwiched between layers of earthy substances to promote the safety of the motorist: the levers used by the chauffeur, and the wheels on which the car runs, are seen as extensions of human limbs; they are inventions of man to help him to move more effectively.

The lack of a biological outlook leads to some strange omissions when teaching about scientific phenomena. For example, capillary attraction is, in many schools, omitted altogether; in many courses on the science of everyday life, its action is illustrated only from such things as fountain-pens and blotting-paper. The biological outlook would remind us that our very existence depends on the action of capillary attraction on a gigantic scale in the tiny spaces between soil particles. For children, blotting-paper is of course an interesting and easily understood example, but this does not justify us in stopping short of the most important example of capillary attraction in the world. Again, the making of oxygen by laboratory methods is taught almost universally, but the greatest and most important method of making oxygen —by green plants in sunlight—is often neglected. One last example: chemical change is generally illustrated by a useful experiment on the making of iron sulphide, but the making of protoplasm, which involves what is probably the most wonderful chemical change in the world, is seldom mentioned.

Examples of the beneficial effect of the biological orientation of science could be multiplied indefinitely. Enough has been said, however, to show how it transforms school science, even that which deserves the title Everyday Science, into something more vital—the Science of Living; how it prevents us from concentrating our attention exclusively on interesting but relatively trivial everyday examples of the working of Nature, to the neglect of other examples which are more important, more widespread, and more wonderful.

### The Biological Approach and Coherence.

The biological approach will help us to solve many difficult problems in teaching science in senior schools. We have shown how it acts as a unifier, bringing together into one whole many otherwise diverse subjects. This of itself will go a long way towards solving the difficult problem of giving a comprehensive course in the very limited time available. The isolated items contained in our analysis of the course in Chapter V appear to be a bewildering multiplicity; fit them into the pattern of a course on living and the chaos disappears. This is an example of the ability of the human mind to grasp a pattern. It is similar to the problem of grasping the number of dots on a domino; double nine is recognized at a glance, but eighteen dots scattered indiscriminately on a piece of paper would have to be carefully counted. Or, to take another example, we should find great difficulty in learning a tune if we studied one bar to-day, another bar to-morrow, and then learned to join them together next week. The better method is to get a grasp at the outset of the pattern or tune as a whole. Appreciation of the full significance of the elements can only come later by a process of analysis. This is the way the human mind works; it grasps "wholes" and then proceeds to analyse. The learning of science is no exception; we must present a coherent whole, and then proceed to see what is in it. Any attempt at working in the reverse way leads to a view of science which must be either narrow or hazy.

The action of the biological approach as a unifier removes another difficulty. It is often asserted that general science must fail because of its superficiality. We might reply that the danger of superficiality or lack of depth is no greater than that of the yawning and unexpected chasms which tend to occur when branches of science are taught separately. A thin surface may, in fact, be perfectly safe; it depends on the degree of cohesion between its parts. Science in senior schools is bound to be relatively superficial; the biological approach ensures that it at least has the merit of being coherent.

## Difficulties in Teaching about Biological Topics.

The biological approach to science as a whole is also, we suggest, the best solution of many of the difficulties felt by practical teachers in face of much modern propaganda in favour of biology for boys and girls. We will take it as axiomatic that the position of biology in education needs strengthening. But an attempt to introduce biology as a separate subject into senior schools would, in our opinion, be a profound mistake. Even if a course in biology were desirable, it is not at present practicable owing to lack of time and equipment, and in most schools of qualified teachers. It is not, however, desirable. Biology is a subject with a difficult foreign terminology; some of its theories are still in the throes of controversy and many of them rest on data which it is not possible for average children to grasp before the age of fourteen. As a subject for senior schools, there is real danger therefore that at one extreme it may remain in the merely descriptive stage of junior-school nature study; at the other extreme, it may develop into a more arid and unreal subject than many of the present science courses consisting of physics and chemistry for boys, and of physiology and hygiene for girls. It would be unwise for schools lightly to abandon the science they are already doing, in many instances very competently. It is not a revolution in content which is required so much as in outlook. The new orientation we are advocating would lead girls' schools to broaden the basis of their present treatment of physiology and hygiene by introducing the requisite amount of physical science; it would prevent boys' schools from stopping short at illustrations taken exclusively from inanimate Nature. The whole of the science in senior schools would acquire a definitely biological flavour, but it would not be biology.

Biology as a subject for senior schools presents another type of difficulty. Many teachers shrink from demonstrating dissections, and to many " sensitive " adolescent pupils such work would be physically revolting. Logically there may be no difference between cutting up meat in the cookery centre and dissecting a frog in the science room; psychologically there is a difference. It is no answer to say that this " squeamishness " is the result of unnecessary repressions in early childhood and is avoidable. As practical teachers we have to face the fact that it exists. In many cases, it exists to such an extent that difficulty is felt in dealing with internal organs even by means of pictures. And closely allied is the difficulty felt almost universally in dealing with questions of mammalian and especially human reproduction. It is true that all these subjects are in modern homes dealt with more frankly and more naturally than they were in Victorian times. It is not, however, the function of science teachers to try to force the pace in this matter, for grave social and moral issues are involved. It is necessary also to point out here that a fervid interest in the realistic teaching of physiological details may denote a mental state no more healthy than that of a very prudish person who would shun the subject altogether.

The foregoing counsel of moderation should not, however, be interpreted as an exhortation to omit important questions because they are difficult. We suggest that if science is taught as a whole, items from biological science being raised cheek by jowl with relevant items from physical science, it will be possible to introduce naturally and without embarrassment many matters which in a different context might be objectionable. For example, if the solubility of salts has been studied in connexion with the feeding of plants, a study of digestion follows naturally as a similar process in connexion with the feeding of animals. To continue the illustration, the separation of the undigested portion of food can then be taught in close connexion with filtration and the separation of sediments.

The study of reproduction furnishes another illustration. This subject can be taught as an example of growth, and be linked up with the mysteries of cell division, and to go one step farther, with the wonders of chemical change. This policy has often been advocated in connexion with sex teaching in so far as we are told to teach about animals and plants together. We suggest that in all biological teaching in senior schools, it is a good plan not merely to deal with animals and plants together, but wherever possible to go farther and link up the biological subjects with similar subjects in the inorganic or physical world. Of course, digestion is more than solution, and the making of protoplasm is not an ordinary chemical change which men can effect in a laboratory. But the fact that biological processes contrast with physical processes in the degree of their intricacy is very useful, for it enables us to lift these subjects to some extent out of the sphere of guilty curiosity into the realm of wonder.

But when all is said and done, we must recognize that for ordinary people (those who are not specialists in the subject) a study of many physiological matters will tend to have an emotional flavour different from that which accompanies the study, say, of an electric motor. Speaking generally, it is not desirable, especially in class teaching, to give physiological details great prominence. Nor is it necessary. Children in senior schools can learn all the physiology they need without seeing dissections; there is indeed much to be said for using nothing more than plain diagrams when teaching about internal arrangements (see, for example, fig. 1).

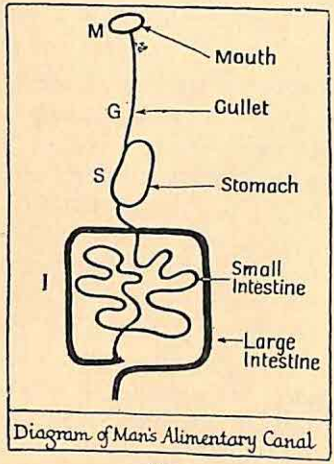

Fig. 1
(From *E.G.S. II*, p. 28)

## Historical and Modern Approaches to Items of Science.

We must now turn our attention to methods of approaching particular items in the course. In many instances, the approach ought to be determined by local circumstances, but it may be helpful to point out and illustrate two of the more important possibilities.

One method is to approach a subject in the way adopted by the pioneers; we will call this the historical approach. The argument is that children are likely to experience the same difficulties as the race experienced; that they are likely to be led astray by the same problems which led scientific pioneers astray. Other things being equal, this is probably true. But in our modern world other things are often by no means equal, and as a result it is often more natural and useful to approach particular items by means of striking applications in the outside world; a modern approach is often preferable to the historical approach. Thus, we have suggested that the Principle of Archimedes should be approached by a consideration of the question: Why do iron ships float? On the other hand, there is nothing in modern applications of fire which suggests a better approach to the theory of combustion than the historical one. Children, as a result of observing fire, still think, as Stahl and his predecessors thought, that when things burn they lose something. But even in this instance, as we have suggested (p. 31), limitations imposed by the short length of pupils' school life, and by their relative lack of intelligence, may make it necessary to short-circuit the historical development. We conclude that the historical method is sometimes but not always a useful approach and that it is seldom if ever possible to follow it in all its details. We cannot afford to allow pupils to blunder into all the pitfalls of pioneers, and we cannot afford to neglect the interests of modern children in the applications of science they see around them.

Although we may generally choose a modern in preference to the historical approach, it would not be in accordance with the spirit of the science we are advocating if we neglected opportunities for referring to the history of science. This is another obvious way of increasing the human interest of the subject. We suggest the making of a time-chart (see fig. 2), and the relating of interesting stories about scientific discoveries throughout the course.

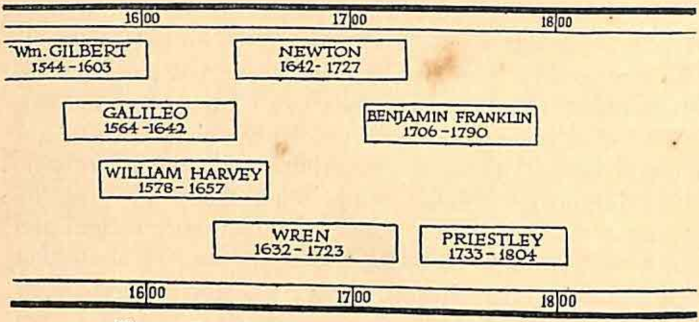

Fig. 2.—Part of a Science Time Chart (in the making)
(From *E.G.S. III*, p. 6)

## The Academic Approach to Items of Science.

A third type of approach to particular items of science may be called the academic approach. For example, a study of electricity may be started by describing various kinds of cells, and by doing laboratory experiments on the magnetic effects of currents. Then, after the necessary science has been taught, its applications are considered. This method, though still often used in schools, has little to recommend it. Children, and especially average children, will learn much more surely if we adopt a modern approach, starting with applications from the outside world and extracting the science from them. Thus electricity may be approached by studying an electric bell, heat by studying heat engines, pulleys by studying clothes-racks and electric-light pendants. If we adopt a biological approach to science as a whole, it will be found that when dealing with individual items we are inevitably led to abandon the academic approach in favour of a modern or a historical one.

## Science from a Biological Point of View.

The biological approach does not prevent us from using applications taken from inanimate Nature. Although, for example, it is possible to approach the Principle of Archimedes by a consideration of the problems of living creatures moving in water, this would not, perhaps, be the best policy to adopt in a school situated in dockland, where boys at least would be very interested in iron ships. But iron ships can and should be treated from a biological standpoint. To a biologically-minded teacher, they are not merely illustrations of an important principle in physics, nor are they merely arresting examples of the application of science to everyday life. They are a necessary element in the process of living in modern times, and they must therefore form part of the pattern of any course on the science of living; in our illustrative course, they fit naturally and inevitably into the feeding and moving sections. In the First Year, pupils study foods brought from sunny lands across the sea; in the Second Year, they study steam engines as a means of increasing our power of moving; in the Third Year these two topics are considered together, and the topic of iron ships, with its hitherto unanswered question of how they float, is seen in its proper perspective.

In conclusion, we would emphasize that the science of living advocated in this book is not biology, nor is it hygiene, nor is it identical with what is usually called everyday science. It is everyday science studied from a biological point of view. In arranging a course in science it is of fundamental importance to have a point of view; that is the virtue of courses in separate branches of science and is one reason why they survive. In many courses of general or everyday science, the topics are selected in more or less indiscriminate order merely because they are arresting; in a course of real general science, the same arresting topics may be selected, but each one falls inevitably into its place as a necessary part of a prearranged pattern. The one scheme tends to be a collection of unrelated topics, the other a unity of ordered and related parts.

## CHAPTER VII

# Observing and Experimenting

Observing and experimenting must form the backbone of any effective course of science teaching. Experiments are necessary to enable pupils to observe one result at a time factors irrelevant to the purpose of the moment are as far as possible eliminated in such a way that observations are focused on the one question at issue. For example, pupils have for eleven years seen people breathing, but until they perform experiments, they cannot discover that the air breathed out contains more carbon dioxide than the air breathed in. For the purpose of these experiments, the facts that expired air is warm and moist, that it can be exhaled slowly or fast, are neglected; attention is concentrated on one issue. This brings us at once to the heart of the subject of experimenting; real experimental work focuses the attention.

Preparing apparatus and performing experiments consume time, the expenditure of which can only be justified if it leads to the economical learning of science. Now it is very easy to spend a great deal of time on practical work in science and achieve very little learning. This is bound to happen unless the work has a purpose which is clearly grasped by the pupils so that their observations are focused on essentials.

### **" Discovery " Experiments.**

The purpose of an experiment is generally to find out what happens rather than to show what happens. It is, for example, contrary to the spirit of science to tell children that we are going to show that when magnesium burns it increases in weight. A preliminary discussion of burning would rather lead them to wonder whether the " ash " does not weigh less; in this case the experiment would be proposed to find an answer to the question: Does magnesium lose anything in weight when it burns? (See *E.G.S. II*, pp. 6–7.) Whatever method is used to introduce an experiment, whether it is done by oral discussion or by the printed word, the essential purpose of the experiment should be crystallized out into a short form of words before the experiment begins. It can often be done most concisely by means of a question, thus:

(*a*) Is there any difference between the air taken in and that which is breathed out? (*E.G.S. I*, p. 8.)

(*b*) Is there any air in water for fish to breathe? (*E.G.S. I*, p. 14.)

It is further necessary to keep these sign-post questions in front of the pupils while the experiments are in progress. This can be done by a note on the blackboard or in the pupils' notebooks, and by rallying back to it at frequent intervals. This is particularly necessary for standing experiments which must be watched for days; such experiments ought to be plainly labelled, e.g.:

(*a*) Do seeds breathe?

(*b*) What happens when a water-plant feeds on carbon dioxide?

(*c*) What makes iron rusty?

Another useful device for keeping the purpose of an experiment clearly before pupils is that of oral discussion as the experiment is prepared and done. By means of such discussions, it is sometimes possible to get pupils to suggest how an experiment shall be performed. Unfortunately there is not time to use this method always, and it is often necessary to give directions. These directions should, however, contain the minimum of detailed guidance; they should always be preceded by some discussion designed to make the pupils think, and if possible they should not disclose the result. The following example illustrates these principles:

Most metals do not burn in air, but we have learnt that, by heating mercury gently for a long time, it is possible to make it combine with the oxygen in the air. In the same way, it is possible to make lead oxide and tin oxide. When you stop to think about these changes, it seems very wonderful that hard metals should combine with an airy gas to form coloured powders. And yet all around, you have daily seen one metal changing into powder. Why does iron rust? Set up the following experiments and watch them daily for a week:

*Experiments* (i)–(v).—To find what makes iron rusty. (Use bright iron nails.)

(i) Keep some of the nails in dry air. (This is one way of doing it: Vaseline the rim of a bell-jar and place it on a piece of plate glass. Inside, place a saucer containing some calcium chloride, a salt which will absorb the water vapour from the air. Make a bridge over the saucer, and on the bridge place another saucer containing the nails.) *N.B.*—Everything used in this experiment must be well dried first.

(ii) Keep some of the nails in airless water. (See experiment 18, Book I, p. 14.)

(iii) Keep some of the nails in water which contains air.

(iv) Keep some of the nails in moist air. (You can invent your own ways of doing experiments (ii)–(iv).)

(v) Sprinkle some iron filings on the inside of a wet gas-jar or a long tube. Invert the jar or tube in water (see fig. 3). (*E.G.S. II*, pp. 15–16.)

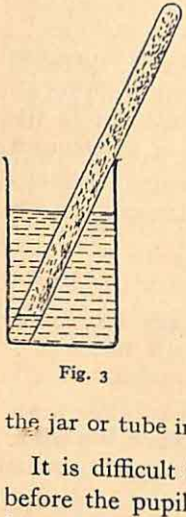

Fig. 3

It is difficult in a textbook to avoid disclosing the results before the pupils have performed the experiments. Where, however, the results are not immediately forthcoming, as in the above example, it is possible to take up another topic both in the textbook and in actual teaching, returning to discuss the results of the experiment a few pages farther on in the book, a few days later in time. The experiments quoted above are followed in the textbook by sections on gas-fires, composition of water, and the preparation of hydrogen, so that the pupil does not necessarily see the results of his experiments in print until he has actually seen them happen in the experiment, and has had a chance of drawing his own conclusions.

### "Appreciation" Experiments.

Although the great majority of experiments are designed to help pupils to "find out", some may usefully be done to deepen appreciation of a fact already known. One example is given on pp. 110-111; another example is the following:

> We say we can see a shadow of a branch on the road. We really see a part of the road reflecting less light than the other parts. This part looks dark and we call it a shadow. As you can see on a misty night, the shade is not only on the road; it is a dark space between the tree and the road. You can prove to yourself that shade fills the space behind an opaque object by a simple experiment:
>
> Suspend an opaque object in front of a light, and notice where its shadow falls. Then place a sheet of white paper between the object and its shadow, and so find out where the shade really is. (*E.G.S. I*, p. 87.)

In this category of "appreciation" as distinct from "discovery" experiments, we would place also those experiments which are repeated. It is too often taken for granted that an experiment once seen is never forgotten. It is true that "doing" is generally more effective than "saying" or "hearing" or "reading", but it is nevertheless valuable to include the repetition of important experiments when revising work in science. Sometimes it may be sufficient to have the apparatus and go through the actions without really performing the experiment. This is certainly better than merely talking about it without the apparatus. We can in this matter learn from Faraday. If he wanted to say in a lecture that a stone when released falls to the ground, he would actually let one fall; if he talked about green plants assimilating carbon, he would produce a plant as he talked.

### "Mystery" Experiments.

We have stressed the fact that it is necessary for pupils to understand the purpose of all experimental work done in science lessons, for unless they do, their work may be of very little intellectual value. There are, however, rare occasions when a " mystery " experiment can be made very effective. When, for example, children are studying soil, they discover its chief inanimate constituents by orthodox purposeful experiments. They do not suspect that it contains anything alive, so we set up the following experiments, frankly telling them that they will understand later why we have done them.

*Two mystery experiments with soil*

(*a*) Divide a small sample of garden soil into two parts. Bake one well in a tin lid over the bunsen burner.

Put a little fresh milk into two flasks; plug the necks loosely with cotton-wool, and bring them carefully to the boil. When the milk is cold, add a little baked soil to one, and the same amount of unbaked soil to the other. Examine next day.

(*b*) Put a little lime-water into two flasks. Cork them both up, but in one of them suspend above the lime-water a small muslin bag containing a little damp garden soil. Examine next day. (*E.G.S. II*, p. 38.)

The next day they see the results; eight pages farther on in the textbook they read about the wonderful tiny plants, called bacteria, which soil contains.

## The Values of Demonstration Experiments.

We have so far said nothing about one question in connexion with experimenting which has in the past provoked a great deal of discussion—Should experiments be done by the teacher or by the pupils? It may be said at once that the problem it raises is not as important or as urgent as the problem of making experimental work purposeful. It is a question to which no single answer can be given; it is indeed almost equal to asking whether in oral lessons the teacher or the pupils should talk. Demonstration and individual experiments both have their values, and whether experiments shall be done one way or the other is a question which each teacher must answer for himself in connexion with each particular experiment in the conditions obtaining in his school. It should also be remembered that there are methods intermediate between the two extremes suggested by the question; a wise teacher demonstrating an experiment will always utilize the services of individual pupils as much as possible.

If, as suggested in the previous chapters of this book, a wide course of science is followed, a great many of the necessary experiments will have to be done by the teacher owing to limitations of time and apparatus. In many schools, the facilities for individual work are also limited, and in most senior schools the large size of classes makes individual work difficult. Demonstration experiments should not, however, be regarded as merely poor substitutes for individual ones. Dangerous experiments, such as the making of hydrogen or those involving the use of phosphorus or strong acids, should obviously be done by the teacher. Some experiments have a striking result, which is most effective if witnessed by a whole class together—for example, the fading of the sound of an electric bell ringing in the receiver of an air-pump as the air is extracted. Other experiments need skilful manipulation of apparatus and are consequently most effective if demonstrated—for example, the experiment of making a barometer with a Torricellian tube. Again, it is obviously unnecessary and impracticable to multiply unduly some of the standing experiments which have to be observed over a period of time, though some of them furnish good examples of experiments which may be done under a group system. For example, it may be practicable to set up four group experiments on the feeding of a water plant with carbon dioxide and put them in places where they will get very different amounts of sunlight.

Apart from these special cases, demonstration experiments have other definite advantages. Being more skilfully performed than is possible by children, the results are often more conclusive. When children perform experiments, their attention is often distracted by non-essentials, sometimes by difficulties of manipulation; when a teacher demonstrates, their minds are free to concentrate on essentials, and the teacher is able by provoking discussion to keep the purpose of the experiment in the forefront. As a means of preparing children for individual practical work, demonstrations have an important value especially in the early stages of a course, for they provide opportunities for teaching pupils how to take care of and manipulate apparatus.

It will be seen, therefore, that not only on grounds of expediency but also on grounds of real educational value, demonstration experiments must play a large part in science teaching. The proportion of demonstration work to individual work will naturally vary according to local circumstances, but, generally speaking, it is probably true to say that most of the experimental work done in senior schools will be more of the nature of demonstrations than of individual experimenting.

## The Values of Individual Experiments.

In emphasizing the value of demonstration work, it is not intended to belittle the importance of individual experimenting, nor to underestimate the possibilities of organizing it under senior-school conditions. An experiment successfully performed by a boy himself has a different value from the same experiment seen from a distance. For example, a boy who has actually held a glowing splint in a test-tube full of oxygen and has felt it quiver as it burst into flame has a keener appreciation of the vigour with which oxygen "supports combustion" than one who has merely seen it from the back of a class. Similarly, a pupil who has actually experimented with magnets and compass needles is in a much better position to understand how electric motors work than one who has merely watched experiments on magnetic attraction and repulsion. Speaking generally, individual experimenting gives a pupil a feeling of intimacy with scientific phenomena which he can never get by merely watching. It often brings him up against difficulties which are not realized when he follows a skilful demonstration, and it may, therefore, help him to appreciate some of the finer points of demonstration experiments. For these reasons, all senior-school pupils should have some experience of actual experimenting.

## The Organization of Individual Work.

With classes of forty, individual practical work is admittedly very difficult to organize. There can only be a limited supply of apparatus. One method of overcoming this difficulty is by setting the class to work in pairs at a number of different experiments, the directions being given on cards. We have in this book stressed the importance of pupils studying science as a coherent whole arranged in a definite course. A card system under which experiments on all parts of a course may be in progress at the same time is clearly incompatible with this policy, and is therefore not recommended. It is, however, possible to organize an occasional individual work period in which a number of experiments, all bearing on one topic, are being performed, and for this purpose instruction cards are useful. Such an arrangement is an excellent way of revising and applying science which has already been taught. For example, when the topic of engines has been completed, it is not difficult to find from ten to twenty experiments on heat which are suitable for individual work. The less able pupils would be required merely to repeat some simple experiments which they have already seen demonstrated:

(*a*) Why is hot air lighter than cold air? Find what happens when air is heated. (*E.G.S. II*, p. 78.)

(*b*) Compare the time it takes to bring some water to the boil (i.e. to boiling-point) with the time it then takes to change it into steam.

Use an aluminium saucepan with about half a pint of water. Keep the flame the same all the time and shield it from draughts. (*E.G.S. II*, p. 81.)

For the brighter pupils, the experiments might well be given in the form of problems, requiring them to think out their own form of experiment:

(*c*) Find the boiling-point of the given liquid.

(*d*) Compare the heating value of the two given bunsen burners.

(*e*) Which of the two given liquids requires more heat to raise its temperature 10° F.?

When all the work in science has to be done with large classes, there is much to be said for teaching by demonstration experiments and using individual experiments chiefly as a means of revision and application.

The possibilities of organizing half-classes for practical work should not be lost sight of. Even if half-classes cannot be adopted as a regular plan, it is at least possible to arrange them occasionally either by massing pupils for work in some other subjects, or by setting one half-class to study privately. The latter device can legitimately be used by the science teacher himself, but it is not a plan which should be adopted regularly; it would, for example, be an unwise use of a weekly hour lesson for half the class to be confined to note-writing and textbook study every alternate week.

A plan which is sometimes feasible is to set up an experiment on a table in the ordinary classroom and allow boys to come out either individually or in pairs at odd moments during the week to perform it. This is a device particularly useful when the science teacher wants all boys to observe something under a microscope.

Perhaps the most promising of all suggestions for giving senior-school pupils some experience of experimenting is to encourage it as a home hobby. To this end, as many experiments as possible in school should be done with simple homely apparatus, e.g.:

(*a*) Test small samples of common foodstuffs to see if they contain fat. The following are suitable kinds: nuts; herring; lean meat; salt; haricot beans; egg yolk; white of egg.

A convenient way of applying heat is to put the food between two pieces of blotting-paper and use a hot iron. Crush the hard foodstuffs before heating. (*E.G.S. I*, p. 43.)

(*b*) Examine an egg whisk (the kind which works with cogged wheels).

(i) Which turns faster—the driving wheel or the small wheels?

(ii) Find how many times the small wheels turn while you turn the driving wheel once. Try to explain the result.

(Count the number of cogs on each wheel.)

(iii) Compare the speed of revolution of the two small wheels. (Count the cogs on each.) (*E.G.S.* II, p. 64.)

Of the 262 experiments suggested in the Pupils' Books for the course outlined, no fewer than 109 could be performed at home with simple apparatus such as tumblers, saucepans, candles, nails, magnets, mirrors, and pocket-lamp batteries. This high proportion is partly due to the special nature of the proposed course, and reminds us that if we devise our science course with the child himself as the centre, we open up a wide field of possible experiments requiring very little apparatus. The following are examples:

(*c*) Look in a mirror in a fairly strong light. Cover one of your eyes with a dark cloth to shut out the light. Remove the cloth, quickly open your eye and watch the pupil in the mirror. (*E.G.S. I*, p. 76.)

(*d*) Next time you are having a bath, turn on the tap and put one ear under water. What do you hear? Turn off the tap and drop a coin or small stone into the water, while keeping your ear under the surface. (*E.G.S. I*, p. 101.)

(*e*) Try to find where your salivary glands are by moving the tip of your tongue about inside your mouth.

Think about your favourite pudding or fruit. Your mouth "waters"; what does this mean?

(*f*) Chew a piece of bread or potato for a minute or two. Notice what you taste. (*E.G.S. II*, p. 26.)

The possibilities of experimenting at home do not, however, absolve us from providing facilities for individual experimenting in school. A science teacher cannot hope to inspire every pupil to do experiments at home, and in many homes the simplest experiment is practically impossible.

### Quantitative Experiments.

We have already (p. 12) expressed the view that, for children, science does not consist of accurate measurement, and we have suggested (p. 21 and p. 26) that in senior schools very little detailed quantitative work need be done. If this principle is accepted, a great many time-consuming experiments can be omitted. A chemical balance, for example, is seldom required, and when used, the method of counter-balancing is often sufficient (see p. 30). Much of the necessary measurement in science for senior schools is of a rough qualitative kind—a determination of more or less, larger or smaller, nearer or farther. Thus, when levers are introduced, poles should be used to lift really heavy weights. The pupils then need no measuring apparatus to discover that the farther it is applied from the fulcrum, the less is the force they need to exert. This is obviously a type of experiment which should be done by each individual before the idea is refined in a demonstration lesson where measurements are made, using spring balances or weights.

### Observation: the result of Interest and Knowledge.

Experimenting in science is not the only way of focusing pupils' observations. Interest and knowledge of a specialized kind have the same effect, and as a science course progresses, the pupils will be capable of observing many examples of scientific phenomena all around them. It is not always possible to arrange for the necessary observations to be made in the classroom, and in such cases pupils should be given some guidance in the form of directions or questions, so that they may observe out of school, e.g.:

(*a*) Why do we take precautions to prevent iron from rusting? (Look about for examples of rusty iron.) (*E.G.S. II*, p. 22.)

(*b*) Do birds and animals use atmospheric pressure when drinking? (Notice how dogs, horses, cats, and birds drink.) (*E.G.S. III*, p. 22.)

It is a good plan also to pause occasionally in order to observe the working of scientific processes in our ordinary daily surroundings in the science room; a hinge is creaking, windows are rattling, dust is moving, a fly is crawling up the window.

In addition to this type of scientific process which goes on in any science room without any special intervention by the teacher, it is very desirable to enrich the environment by keeping interesting examples of living things—worms, fish, tadpoles, caterpillars, snails, sprouting seeds and growing plants. The teacher need not fear that this means nothing but a reversion to junior-school nature study; as the pupils learn the science of breathing, feeding, moving, and sensing, they will observe with new and quickened interest the life processes of all these living things. The teacher and the pupils will also find them very useful as illustrations in practically every section of the course.

From time to time, educational visits should be made to places of specialized scientific interest outside the classroom—to power-stations, gas-works, milk depots, factories, and museums.

Finally, as we suggested on p. 28 and p. 45, a walk along any common street will provide the opportunity for revising most of the science of living. Mention should also be made of pictures, for when the science of living is being studied, hardly any picture can be irrelevant. Films depicting processes, both natural and artificial, are especially valuable.

The advantage of having some coherent plan for a science course is very clearly seen in all this observational work; each and every item observed in the medley of a street scene can quickly be fitted into its place in the pattern. There is no scene, no place, no happening which is devoid of scientific interest once we have studied in broad outline the science of living in its four aspects—breathing, feeding, moving, and sensing.

**Books for Reference.**—The construction of working models in handicraft lessons is a very useful way of reinforcing the teaching of science, and it is one method of increasing the stock of apparatus for experimenting. Boys' schools can, in return for other kinds of help, be of real service to girls' schools in this matter. The following cheap handbooks contain excellent suggestions for such constructional work. They contain titles such as Telephones and Microphones, Small Electric Motors, Camera Making, Electric Clocks.

"*Model Engineer*" *Series of Handbooks* (Percival Marshall).
*Work Handbooks* (Cassell).

Science teachers will find it helpful to make a special study of the psychology of observation. The following are useful references:

*Herbartian Psychology*, Chapter VI, *Observation*, J. Adams (Heath). *Educational Psychology*, Chapter III, *Observation*, C. Fox (Kegan Paul). *A Primer of Teaching Practice*, Chapters VI, XI, XII, Green & Birchenough (Longmans).

## CHAPTER VIII

# Talking and Reading

In the previous chapter we have emphasized the importance of observing and experimenting as a method of studying science. We have incidentally mentioned the value of oral discussion as a means of keeping the purpose of practical work clearly before pupils, and, as we shall show in Chapter X, there is equal need for oral discussion after the observations have been made. But in addition to practical work with its necessary accompaniment of discussion, there is need in science teaching for a great deal of talking and reading And, as in observing and experimenting, both teachers and pupils have their parts to play.

### Class Discussions.

Perhaps the most important kind of talking is conversation. In ordinary life, so much conversation consists merely of "small talk" that we are apt to forget what an important educative influence conversation can be. Conversing about scientific subjects should play an important part in science teaching. For want of a less ambiguous title we will call these conversations discussions. There should be discussion in all science lessons, even in those where practical work predominates, for incidental conversations with individuals or with groups of pupils doing practical work can be most valuable. But apart from the usual type of science lesson, some time can profitably be spent in discussing special problems. Many of them will arise naturally out of the topics being studied; others will be suggested by topical events which are either directly experienced or are reported in the newspapers. The number of suitable subjects is unlimited; the Pupils' Books contain upwards of two hundred suggestions of which the following are examples:

(*a*) What are the chief advantages and disadvantages of friction in the home? (*E.G.S. I*, p. 61.)

(*b*) Notice all the different kinds of interior lighting arrangements you can (in shops, schools, and houses). Which are least likely to injure our eyes? (*E.G.S. I*, p. 97.)

(*c*) The advantages and disadvantages of the wearing away of rocks and stone.
*Consider:* the formation of soil; landslides; the silting up of rivers; the wearing away of valuable stone buildings. (*E.G.S. II*, p. 43.)

(*d*) If an electric bell will not ring, what are the possible causes of failure? (*E.G.S. III*, p. 78.)

### Five-minute Lectures.

Another important type of talking is the five-minute lecture given by pupils. If the audience is encouraged to ask questions, some lively conversations will often ensue. The Pupils' Books contain about one hundred suggested subjects; the following are typical examples:

(*a*) Divers and diving devices. (*b*) Liquid air. (*c*) A visit to a steel-works. (*d*) How to make a periscope. (*e*) Sunlight for health. (*f*) The history of fire-making. (*g*) The development of flying machines. (*h*) The wonders of coal-tar. (*i*) Submarines. (*j*) The work of Pasteur. (*k*) The story of Faraday.

### A Science Library.

It will not be possible for the teacher in the ordinary course of his science lessons to deal with more than a few of the applications of science in which children are interested, nor is it necessary to do so. Different individuals will be interested in different subjects, and the teacher's function is to refer pupils to appropriate books for the information they are seeking. A science library for children is essential. An adequate collection of suitable books cannot be acquired all at once, but if only ten new books are added annually, satisfactory progress can be made, especially if help can be obtained from a local public library. The choice of books is to-day almost unlimited, and little purpose would be served by giving a miscellaneous list here. Lists of suitable books for each section of the suggested science course are given at the ends of the various chapters in the Pupils' Books.[1]

### Science and the Newspaper.

A type of reading material especially useful for teachers of science is contained in the modern newspaper. In order to appreciate what a wealth of interesting scientific information is set out daily in this way, readers are recommended to compile a collection of relevant cuttings from one newspaper over a period of time. For example, during a period of twelve months from December 1931 to November 1932, no fewer than five hundred items of news bearing on scientific subjects appeared in *The Times* newspaper. Hardly a day passed without some reference to science, and during the year, one or more references occurred in connexion with practically every individual item contained in the comprehensive science course outlined in earlier chapters of this book. The most frequent type of scientific news occurred in accounts of the work of various associations. More than fifty of these associations were mentioned, ranging over a great variety of subjects such as engineering, brewing, agriculture, greenkeeping, forestry, vegetarianism, fuel, gliding, radiology, and roads. Most of these associations were interested in research, as, for example, the Fuel Research Board, the Medical Research Council, the Welsh Plant Breeding Station, and the Department of Scientific and Industrial Research. Many of them published reports which were summarized in the newspaper; some of them held public meetings which were reported. Another type of scientific news consisted of accounts of notable events; the following are typical examples taken from the period under review: the death of Sir Ronald Ross; eclipses of the sun and moon; meteoric displays; hurricanes; volcanic eruption in the Andes; tercentenary of the birth of Wren; high barometer readings; Piccard's ten-mile balloon ascent. Then there were accounts of new inventions, discoveries and industries; for example, a new type of carbon dioxide fire-engine; a new kind of accumulator suitable for running electric trains; colloidal fuel; coloured photographs in newspapers; infra-red photography; skywriting; new discoveries about vitamins; developments in the canning industry. Another type of news was contained in correspondence which took the useful form of a debate; for example, on the causes of dental decay, on the reduction of noise, on colour sense in animals. Yet another type was contained in accounts of accidents; for example, avoidable electric shocks, accidents due to bad illumination, explosions.

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[1] A very useful classified list of books will also be found in an appendix to *Teaching Science in Schools*, J. Brown (Univ. of Lond. Press).

It is not possible in a short space to give any adequate idea of the information contained in five hundred newspaper cuttings, but we will take two subjects at random as illustrations.

(*a*) *The Pollution of the Atmosphere.*—This subject was debated at meetings in connexion with the National Smoke Abatement Society. We were informed that the elimination of smoke would reduce the incidence of bronchitis and save pounds in the cost of cleaning. In one industrial city, we were told, smoke cuts off 50 per cent of the sun's rays and in one year it adds £242,000 to the cost of the citizens' wash-tubs. The subject was authoritatively dealt with in the *17th Report on Atmospheric Pollution* issued by the Department of Scientific and Industrial Research (H.M.S.O.). From the newspaper summary we learn that in an average industrial district 200–300 tons of solid matter were deposited per square mile in the year ending March 1931, and that the pollution from a town 24 miles in diameter would be perceptible at a distance of 60–70 miles. Sulphurous fumes, it has been estimated, do £120,000 damage every year to Government buildings alone. This aspect of the subject was also referred to in another official report on *The Weathering of Natural Building Stones*. There we learn that acid sulphur gases have in some places eaten 9 in. deep into the stonework of York Minster. Another report on *Dust in Card Rooms in the Cotton Industry* told how sickness among operatives had been reduced by the attention paid to methods of reducing cotton dust in factories; in another type of industry, similar work was being done to protect workers from silica dust. A new kind of pollution is carbon monoxide, which forms 5 per cent of the exhaust gases from petrol engines. An average car travelling at 30 m.p.h. emits, we are told, 1 c. ft. of this poisonous gas every minute, and it is claimed that Diesel engines are less dangerous in this respect than petrol engines. In crowded streets with tall buildings, we are warned, there may be real danger in still weather.

(*b*) *The Rusting and Corrosion of Iron.*—In the report on the *Weathering of Building Stones* we find the interesting information that Wren is said to have specified that in his buildings no iron should be within 9 in. of the air. Other news items revealed that practically all the rivets used in shipbuilding in this country are made of iron as it is less liable to corrosion than steel, and that experiments are being made with stainless steel rivets and plates. In one test, stainless steel articles were exposed for 100 days to a varied sequence of weather conditions in a ship sailing between London and Australia. In order to reduce the costs of overhauling, stainless steel is being used experimentally in the manufacture of aeroplanes, and it has been proved suitable for the hulls of flying-boats. An interesting human touch is contained in the news from Sheffield that Mr. Harry Brearley, the discoverer of stainless steel, has presented to the Cutlers' Company an account of how he made his discovery, but it is not to be opened and read until 1960.

Definite information of the kind given in the above illustrations will do much to make science a reality to boys and girls. Newspaper science reminds us that the composition of real air is not exactly the same as that of the ideal air analysed in academic chemistry; it reminds us that the rusting of iron does not merely affect a few iron nails in a laboratory experiment, but that it is a matter of vital importance in the manufacture of ships and aeroplanes. A study of newspaper science is a great help in developing a biological outlook. Makers of newspapers are perhaps quicker to realize the kind of science which makes an appeal to ordinary people than those who study science in laboratories; it is science as it affects the lives of men and women which is valuable as " news ". There are, of course, dangers in newspaper science; these are referred to in Chapter X.

Newspaper science has at least one other value: it helps us to realize the immense amount of thought which is being given in the modern world to invention and research. Much research work is useful and has a cash value; some of it is purely disinterested and may, at any rate for a long time, serve no material ends. It is important to interest senior-school pupils in both types, and to try to develop in them some respect for and sympathy with research workers. Senior-school pupils cannot, of course, understand the details of modern research, whether pure or applied; they can, however, like the average newspaper reader, appreciate the importance of many of its results.

## Various Sources of Scientific Information.

Finally, teachers of science should not neglect the help which they can get from many other forms of literature—from the writings of men of science, of travellers, explorers, and novelists. There are many occasions when the telling of an impressive story or the reading of a striking passage may do much to help pupils to appreciate the wonders of Nature. There are, for example, short passages about earthworms in Darwin's little book, *The Formation of Vegetable Mould through the Action of Earthworms*, and in Gilbert White's *Natural History of Selborne*, with which senior-school pupils should be made familiar. (One such passage has already been quoted, see p. 35.) It is, of course, important that first-hand observations be made in a " wormery " and if possible in a garden, but unless this work is supplemented by vivid description, pupils will leave school with a very inadequate idea of the value of these lowly creatures in the process of living. The same is true of many other scientific topics.

Then there are some important scientific subjects about which it is impossible in school to make observations or to do experiments; it does not follow by any means that all such subjects should be omitted from the course. Senior-school pupils should, for example, hear something about vitamins, radium, and X-rays; there are other occasions on which it is quite legitimate for science teachers to instruct by talking and reading.

In conclusion, we would emphasize the importance of teaching science, as far as is practicable, by the method of discovery; the backbone of the course, as we have said, should be experiment and observation. But when all the possible experimenting has been done, much still remains to be told. No one would be so foolish as to suggest that pupils should derive all their historical and geographical knowledge from first-hand sources; it is almost equally foolish to suggest that they should discover all their knowledge in the vast realm of science by first-hand observation. Experiments and observation in science correspond to practical geography and local history; they should form an important part, but by no means the whole of the course.

**Books for Reference.**—As suggested in this chapter, suitable short extracts for reading in connexion with science lessons can be obtained from a variety of sources:

(*a*) Newspapers and Journals.

(*b*) Books of Travel.

(*c*) Novels; for example: *High Wind in Jamaica*, Richard Hughes; *Faraway*, J. B. Priestley.

(*d*) The Writings of Naturalists and Men of Science; for example: Darwin, Fabre, Faraday, T. H. Huxley, Julian Huxley, Jeans, Richard Jefferies, Ray Lankester, Tyndall, Gilbert White.

A small anthology of extracts is the following: *Pages of Science*, edited by G. Sampson (Methuen).

## CHAPTER IX

# Writing

Pupils' notebooks should not be kept primarily for the information of teachers but for the use of pupils. They should be kept by pupils in schools for the same reason as they are kept by men of science in laboratories; they are a necessary and by no means uninteresting accompaniment to the study of the subject. Whatever notebooks are compiled and whatever is put in them, they are the pupils' property Most children like collecting; here are new, interesting, and useful collections to be made. This is the spirit in which notebook work should, as far as is possible, be done.

### Class Question Books.

The first notebook suggested is a classbook in which pupils may write their scientific questions.

> *A "How and Why" Book.* You can begin at once to write down some of the How's and Why's which have puzzled you. Quite a good plan is to make a Class Question Book. You will have to be patient though, for it may not be possible to get answers to all your questions at once, and there are some questions which even men of science cannot yet answer. (*E.G.S. I*, p. 2.)

Triviality and irrelevance are the dangers. But these child-like failings need to be treated with tolerance and good humour. When the habit of asking questions has been established, then the necessary disciplinary process can be started.

It is a good plan to have the questions written on left-hand pages, reserving the right-hand pages for replies, which will often take the form of references to some books which are accessible or which can be made accessible.

It is important that pupils should learn that there are occasions when questions cannot be answered immediately. Postponed questions may be starred; they will often provide excellent introductions to science lessons when the time comes. A word of warning is perhaps necessary here. The best time to answer a question is when it is asked, and when dealing with an individual child questioner there is much to be said for giving him as satisfactory an answer as possible immediately, with a promise that future work will make the matter clearer. This policy is far more likely to develop real keenness than the policy of putting the questioner off with a superior "You can't understand that yet". The same applies to the policy of meeting a question with a retaliatory question. The Socratic method is very helpful if used in moderation in class teaching, but it is often overdone by zealous teachers dealing with individual children. A sincere question asked by one individual of another deserves a sincere answer given as directly as possible. A postponed question in the type of notebook we are considering will therefore generally be a question, the discussion of which *in class* has been postponed.

### Class Scrapbooks.

A second type of notebook may be described as follows:

> *Class Scrapbook.*—Another interesting thing to do is to make one large scrapbook for the whole class. You can perhaps elect an editor and assistant editors to look after it. But everyone can collect pictures and interesting paragraphs from newspapers and advertisement leaflets. Start now to make a collection about the subject of this chapter. Mount the cuttings on large sheets of brown paper and bind them in loose-leaf files.
>
> You will find it more interesting if you arrange your material according to some plan. For example, the cuttings about breathing might be put into sections for (*a*) human beings, (*b*) animals, (*c*) birds, (*d*) fish, (*e*) plants. You will probably find it necessary to make other sections as you proceed. (*E.G.S. I*, p. 6.)

Little need be added to this description. Unrestrained enthusiasm will lead some pupils astray, and it will be necessary to give occasional warnings against spoiling books for the sake of the collection. The kind of science advocated in this book is so wide that it will be difficult to reject pictures as irrelevant. Any street scene, for example, is at least reminiscent of many science lessons, and if such pictures are submitted, it may be a sign of successful science teaching. That is to say, the pupils may be acquiring some facility in looking out on the world around them through the spectacles of men of science. It is always desirable to have some check, however, and it is suggested that it may become necessary to make a rule that any picture submitted must have some title indicating that it refers to a definite science topic. Of course the title need not be the printed one; if the contributor, by writing a suitable title, can make the picture relevant, so much the better.

## Individual Notebooks.

The third and most important type of notebook is the individual book which each pupil should keep as a useful and interesting record of work done. The more useful and interesting the book is to the pupil, the less burdensome and tedious will the supervision of such books be to the teacher. It is important therefore to keep alive the idea that these books do serve a useful purpose. Pupils should never get the idea that notebooks are a nuisance not only to themselves but also to their teachers. The suggestions which follow are offered with a view to making this counsel of perfection practicable at least in some degree.

The start is all-important. The book itself should be, if possible, a little more dignified than an ordinary exercise book. The pupils should be told that men of science find it useful to make notes of the experiments they do and of the facts they discover,[1] and that they too will find it useful and interesting to keep science notebooks. The first entries, therefore, should relate to matters which are of obvious importance to eager beginners; dictated statements of what constitutes science are, for example, seriously out of place here. The following type of exercise is, however, at least not uninteresting:

*Notebook Exercise.*—As you work through this book, you will find it is useful and interesting to make notes of some of the facts you discover. When you have sets of figures, it is often convenient to tabulate them like this:

---

[1] A reference may be made to the careful records kept by Faraday. Pupils will be interested to know that *Faraday's Diary* is now being published in seven volumes at 12 guineas the set.

RATES OF BREATHING

| Living Creature | Number of Breaths per Minute |
|---|---|
| Myself (sitting down) .. | |
| Myself (" out of breath ") | |
| Man (sitting down) .. | |
| Woman (sitting down) .. | |
| Baby (asleep) .. .. | |
| Baby (awake) .. .. | |
| Dog (asleep) .. .. | |
| Dog (awake) .. .. | |

(*E.G.S. I*, p. 6.)

At no stage should notebook work be too difficult. To require beginners without help to write clear accounts of experiments and concise summaries of knowledge is merely to pile up a large amount of annoying and unnecessary marking; it is certain to give pupils a distaste for note-making, and possibly for science itself. It is a very salutary discipline for those of us who set children exercises in English composition to sit down occasionally and perform the exercises ourselves. A few attempts, particularly at summarizing the knowledge gained in a series of science lessons, will reveal how difficult it is to write satisfactory science notes. But this fact should not lead us to abandon all hope of obtaining "original" notes from average children. It should rather lead us to recognize that the art of writing original notes is one which needs careful and graduated training. At the end of a course in science, a pupil should not merely be the possessor of a good, useful, and interesting notebook, he should also possess the ability to make such a book with the minimum of help. Such an ability may remain with him long after he has outgrown his notebook.

From the outset, the importance of oral work as a form of training for unaided note-writing should be recognized.

In addition to the oral discussions referred to elsewhere (p. 93), there are many incidental opportunities for training in the making of clear statements. During the progress of demonstration experiments, pupils should be required to state the purpose of the experiment, to describe the apparatus, to say what they observe, and finally what they may legitimately infer. It is a good plan, now and then, for the teacher to act the part of a "dumb showman", the pupils doing all the talking as the teacher performs the experiment. A very useful variation, instead of requiring individuals to give an oral answer, is to require all pupils to write down the answer quickly in pencil on scrap paper. There will thus be plenty of scope for practice in original note-making, but, being oral or on scrap paper, it will be corrected orally as the lesson proceeds; this plan has many advantages in early stages both for pupils and teachers.

## Notebook Lists.

A useful kind of original written note which can be started early in a senior-school course is the making of lists. The following are illustrations.

Add as many examples as you can to the following lists:

(i)

| *Living things* | *Openings for breathing* |
|---|---|
| Human beings .. .. .. .. | Nostrils |
| Plants .. .. .. .. | Stomata |

(*E.G.S. I*, p. 19.)

(ii) *Ways of keeping the air clean*

Use smokeless fuel
Make dustless roads

(*E.G.S. I*, p. 20.)

(iii) *Natural sources of*

| (*a*) *Sugar* | (*b*) *Starch* |
|---|---|
| Sugar-cane | Potato |
| Ripe fruits | Maize |

(*E.G.S. I*, p. 34.)

(iv) *Wheels useful when moving things*

(*a*) *Along*
Wheels on carts
Castors on pianos

(*b*) *Up and down*
Clothes-line pulleys
Pulleys in sash window

(*c*) *Round and round*
Water wheels
Potter's wheels

(*E.G.S. II*, p. 60.)

The making of such lists will be intrinsically interesting to many pupils, and the lists themselves may serve several useful teaching purposes. Some, like example (i), may be summaries of knowledge already taught; some, like example (ii), may be lists of everyday applications of scientific knowledge; some, like examples (iii) and (iv), may serve as starting-points for the teaching of new knowledge; others, like example (v) below, may be collections of interesting information from books of reference:

(v) Collect the necessary information and then enter in your notebook a table of interesting facts about the planets. Like this:

| Name of Planet | Diameter (in miles) | Distance from the Sun | Time taken to revolve round the Sun | Number of Moons |
|---|---|---|---|---|
| | | | | |

(*E.G.S. I*, p. 86.)

### Notebook Descriptions of Experiments.

A second type of written record is a description of an experiment. In this work, it is well to have some simple standard form of procedure. Teachers will probably prefer to fix their own details; there are, however, a few general principles worth stating. A description of an experiment should, as a rule, contain (*a*) a clear statement of the purpose of the experiment; (*b*) a description of the apparatus and the experiment; (*c*) a statement of the result observed; (*d*) a statement of the conclusions (if any). The plan of having three columns, with such headings as, What I did, What I saw, What I learned, is unnecessarily rigid. It cramps style and often results in tabulating material which is better dealt with in free composition. The method of tabulation should be reserved for those occasions when, as in the examples quoted on p. 103 and p. 105, it is obviously valuable.

In the early stages, pupils need a good deal of help and guidance in writing descriptions of experiments, and there are many ways of giving this help which are much more valuable than dictation or transcription. The completion method, for example, may be used in various ways:

### (i) ONE METHOD OF MAKING CARBON DIOXIDE

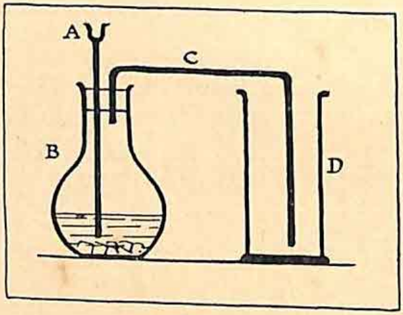

Fig. 4

(carbon dioxide; chips; collected; delivery; flask; dilute; funnel; hydrochloric; jar; marble.)

We made some –1– by pouring a little –2– –3– acid through the –4– A on to some –5– –6– in the –7– B. By means of the –8– tube C we –9– the gas in the –10– D. (*E.G.S. I*, p. 12.)

### (ii) AN EXPERIMENT TO FIND WHETHER FISH MAKE CARBON DIOXIDE

We put a live fish into . . . . . . At the end of a few minutes, . . . . . ., showing that . . . . . . . (*E.G.S. I*, p. 17.)

### (iii) AN EXPERIMENT WITH SPROUTING SEEDS

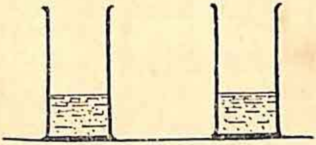

Fig. 5a

Jars A and B contain ......

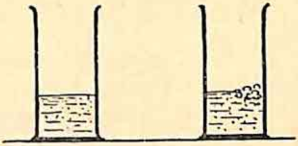

Fig. 5b

We put a handful of ...... into B
At the end of .... days the .......
started ......

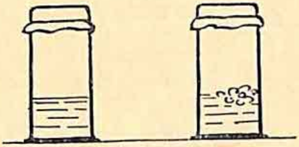

Fig. 5c

We ...... the mouths ........ and
left the jars for ...... hours

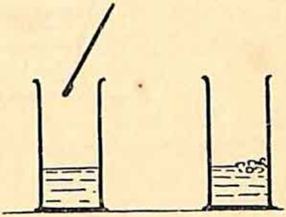

Fig. 5d

By means of a drop of lime-water
on the end of a glass rod, we found
that the amount ........

We know therefore that the sprouting seeds made .......

(*E.G.S. I*, pp. 18–19.)

### (iv) AN EXPERIMENT ON REFRACTION (see p. 108)

(Air; appears; basin; beam; bent; did; entered; eye; I; light not; penny; risen; saw; see; seem; straight; water; Water.)

–1– *in the basin.*—The beam of –2– from the penny travelled all the way in one –3– line. I was standing too far back for any light from the –4– to enter my –5–. Therefore I –6– –7– –8– the penny.

–9– *in the basin.*—The –10– of light from the penny was –11– when it passed from –12– to air. Some light from the penny now –13– my eye. Therefore I –14– the penny although neither –15–, nor the –16–, nor the penny had moved.

*Why does the penny –17– to be higher?*—When we see anything it –18– to be in the direction from which its light enters our eyes. Therefore when we see the penny, it appears to have –19– in the water. (*E.G.S. I*, p. 93.)

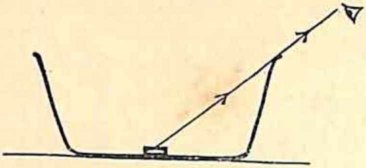

Fig. 6*a*

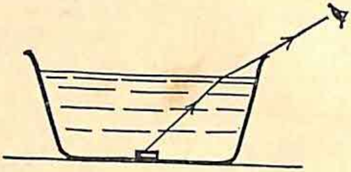

Fig. 6*b*

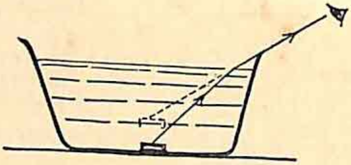

Fig. 6*c*

It will be noticed that in the above examples, suggested as suitable for first-year pupils, no attempt has been made to introduce "note form" or abbreviations. It is probably better to hasten slowly and to introduce difficulties one at a time. During the First Year, it may be enough to concentrate on training the pupils to use the smallest possible number of words. When some facility in concise expression has been achieved, the pupils may be encouraged to abbreviate, thus:

(v) *Expt.* 1, *Bk. II, p.* 7. To find whether magnesium loses "fire-stuff" when it burns.

Placed clean dry crucible (with lid) on balance pan. In cruc. put mag. ribbon. Replaced lid. Balanced cruc. and contents by means of . . . . . . . Heated cruc. . . . . . . . . .

*Result.*—After mag. had burnt, cruc. weighed . . . . . . . than at first. ∴ when mag. burns, it . . . . . . . "fire-stuff"; on the contrary, it . . . . . . . . . (*E.G.S. II*, p. 7.)

No definite suggestions can usefully be given as to when pupils should be expected to write all notes of experiments unaided. It is not simply a question of the pupils' maturity or skill; some experiments, such as example (iv) above, are difficult to describe and a return to detailed guidance is justifiable. Quite early in the First Year, however, the pupils should be encouraged occasionally to attempt original description of easy experiments. They may at first receive some help in the form of preliminary oral discussion or in the form of questions, for example:

(vi) Describe fully what happens when water boils. Your description should contain answers to the following questions:

(*a*) What are the bubbles in boiling water?

(*b*) Are they lighter or heavier than water?

(*c*) What happens to them when they reach the surface of the water?

(*d*) What happens to the vapour when it gets away from the hot flask? Why?

(*e*) What happens to the steam when it gets right away into the air? (*E.G.S. I*, p. 27.)

The chief difficulty in making a record of many experiments is in stating the conclusion. It is true that in describing the experiment, inexperienced pupils are apt to waste time on inessential details. If, however, the directions for performing the experiment are concisely stated, pupils can be taught to avoid this pitfall by following these directions closely in writing their own descriptions. The following is an example where help with the conclusion is all that is necessary in addition to the directions given for doing the experiment:

(vii) *Experiment.*—Stand a convex lens upright in a lump of plasticene. On one side place a lighted candle; on the other side place a screen. Arrange the distances of lens and screen so that you have a clear image of the candle on the screen. Move the candle farther away and find how you have to move the screen in order to keep the image in focus. Notice also how the size of the image changes.

*Notebook Exercise.*—Describe the above experiment. Express the result like this (the initial letters of the missing words are given):

The f—— the object is from a convex lens, the n—— is the image, and the s—— does the image become. (*E.G.S. I*, pp. 96–7.)

It will be noticed in the examples given that the diagrams in every case serve a useful purpose. They are not decorations, and there is no need therefore for elaborate drawings. It is a good plan to train pupils to draw diagrams as far as possible free-hand in ink. If they are drawn reasonably small and enclosed in a frame they look neat, and as long as they indicate essentials clearly, there is no need to worry about poor drawing. For example, in the diagram accompanying example (i) (p. 106), single thick, free-hand lines are quite sufficient to indicate tubes; in the diagram with example (iv), however, the rays of light must obviously be drawn carefully with a ruler. Diagrams should always be drawn in section, thus avoiding the difficulties of drawing ellipses. As a general rule, they should be lettered, and the letters used in the description; in this way many words can be economized.

It will not be possible, nor is it necessary, to describe every experiment in writing. Some are of relatively minor importance; others are only done to deepen appreciation of well-known facts. For example, the following experiments are intended to help pupils to appreciate that an "empty" jar is really full of air:

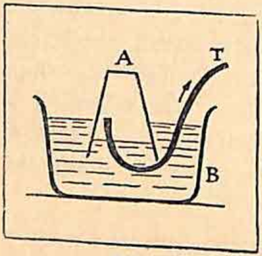

Fig. 7

(*a*) Invert an "empty" glass tumbler A in a deep basin of water B. How far does the water rise in the glass? Why does it not come to the top of the glass however hard you press down?

Use a piece of rubber tubing T, and suck some of the air out of the tumbler. What happens?

(*b*) What will happen if you turn the glass over on its side, keeping the mouth below the surface of the water? Try it. (*E.G.S. I*, pp. 7–8.)

In examples like these, more good is done by repeating and modifying and discussing the experiments than by writing accounts of them. Some experiments, on the other hand, are crucial; they form an essential link in the development of the subject, and it is important to have a notebook record. (Examples have been given on pages 106–108.)

It should be noted that there are methods intermediate between the full written record and no record at all. Instead of describing an experiment, it is sometimes sufficient to draw the apparatus and label it, writing below a short statement of what the experiment teaches.

## Notebook Summaries of Knowledge.

Another useful type of notebook record is a summary of knowledge. The more experimental work which is done, the more necessary it is at frequent intervals to take stock of the progress made, to knit together the various isolated conclusions. There is always a danger lest the intrinsic interest of experiments should swamp the interest in the subject being studied. This subject, it must always be remembered, is science, not experiments. The most important method of ensuring that progress is real, is the method of oral discussion, with individuals, groups, or with whole classes. But it is desirable, in the interests of clear thinking, to crystallize out in the form of summaries the results of these discussions; in the interests of thorough learning, it is desirable for pupils to make some written record of these summaries. Pupils should receive help in compiling summaries, for the work is, generally speaking, too difficult for them to do unaided. If a summary is to be useful, it must be clear and accurate. The completion method is, therefore, again recommended, and for notebook summaries as distinct from accounts of experiments, it is suggested that this method might well be used throughout the course. The following are examples:

*Notebook Summaries.*—Complete the following paragraphs, filling in the right words in the gaps. All the necessary words are given in the list printed in brackets. Use all these words and no others. Notice that the list is arranged in alphabetical order to help you to find quickly whether the word you think you want is there.

### B. 1. BREATHING

(air; breathe; carbon; carbon dioxide; colourless; dilute; extinguished; gas; heavier; increased; lime-water; marble; not; three; vapour; warmed.)

During the time –1– is in our bodies, it is changed in at least –2– ways, viz.,

(*a*) It is –3–.

(*b*) The amount of water –4– in it is –5–.

(*c*) The amount of –6– in it is increased.

Carbon dioxide is the –7– which is made when –8– burns. It can also be made by pouring –9– hydrochloric acid on to some chips of –10–. We ourselves are also continually making carbon dioxide by using inside our bodies the air we –11–.

Carbon dioxide is a –12– odourless gas, and is –13– than air. The gas itself will –14– burn, and if burning things are put in it, the flames are –15–. It is the only known gas which will turn –16– cloudy. (*E.G.S. I*, pp. 11–12.)

### M. 1. MOVING

(able; animals; become; food; grow; increased; lives; living; machines; move; plants; rooted; unlike; Young.)

All –1– things, both –2– and animals, must move in order to feed and –3–. –4– creatures, at the beginning of their –5–, are like plants; they absorb their –6– without having to –7– about to get it. As they grow up, they –8– more and more –9– plants, for instead of being –10– to one spot, they are –11– to move about.

Man has –12– his ability to move by employing –13– and by inventing –14– and engines. (*E.G.S. I*, p. 55.)

### S. 1. SEEING

(books; bounces; enters; eyes; light; lit up; miles; moon; not; people; planets; reflected; second; see; stars; straight; sun; white-hot filaments; yellow flames.)

We only see things when light –1– our –2–.

Some things we see by the –3– they make themselves. Such things are: –4–, –5–, –6–, –7–.

Most things are –8– alight, but we –9– them because they are –10– by light coming from other sources. The light which falls on them –11– off again. Some of this –12– light enters our eyes and so we see the things. Some examples of things we see by reflected light are: –13–, –14–, –15–, –16–.

Light travels at a speed of about 186,000 –17– per –18–. (*E.G.S. I*, p. 86.)

*Notebook Summary.*—Complete the following paragraph (the initial letters of the missing words are given):

### F. 1. FEEDING

Food is n—— to keep us g——, to keep us gr——, and to keep us in r——. (*E.G.S. I*, p. 23.)

It is unnecessary to set out in detail the advantages of the completion method over those of mere transcription or of dictation. It will be noted that the pupils are not relieved altogether of the necessity of thinking; the teacher is, however, relieved of a considerable amount of marking. The completed summaries in the pupils' notebooks will be useful for revision purposes; the uncompleted summaries provided by the teacher or the textbook will be useful in a variety of ways. They can, for example, be used for periodic tests, the pupils writing down the answers within a time-limit which can be progressively reduced each time the test is repeated. The test can be varied by being done orally, again under time limitations; it can be made more difficult by covering up the lists of words.

It must be emphasized that the summaries are intended to be the culmination of a large amount of original work on the part of the pupils. If completion paragraphs are used prematurely without adequate preparation, there is a danger that pupils will acquire merely the shadow instead of the substance; they will learn words when they ought to be assimilating experience and gaining knowledge. This warning is particularly necessary in connexion with the use of another device which may profitably be employed occasionally for all kinds of written notes. It is the method of reproducing a model which has been studied; for example:

*Notebook Summary.*—Study the following summary of what you have learnt; then write it out from memory in your notebook:

*The Essentials of Life*

| *Plants* | *Animals* |
|---|---|
| Air | Air |
| Water | Water |
| Salts | Salts |
| Sunlight | Sunlight |
| Carbon dioxide | Plants |

(*E.G.S. I*, p. 46.)

## Maintaining Interest in Notebook Work.

We have emphasized the idea that pupils should be interested in notebook work, and we have made various suggestions designed to sustain this interest. These suggestions may be summarized by saying that the pupils should be encouraged by help and stimulated by variety. Thus we have suggested that (i) appropriate help be given in order that the task of making entries is at no stage so difficult that the pupils' interest is damped by a sense of failure, and (ii) the notebook entries should be of various kinds, and a variety of devices should be used for giving the required help.

It now remains to make suggestions for keeping before pupils the idea that their notebooks are useful. It will be found helpful to number the pages and compile an index. This will facilitate reference to back work, for when difficulties arise, the first court of appeal should generally be the notebook. A good purpose can also be served by requiring pupils to study, and sometimes to read aloud from their notebooks in order to refresh their memories on a particular point. Finally, if the science course is coherent and concentric as suggested in this book, the notebook of the previous year will often be found useful when in the Second or Third Year previous work is being amplified.

## Economizing Time in Notebook Work.

The methods of note-making outlined in this chapter are in many respects economical of time—for example, the use of free-hand drawing for diagrams; the provision by teachers or textbooks of skeleton notes in the early stages and of skeleton summaries at all stages; the use of abbreviations; the recording of the most important experiments only; the occasional recording by a labelled diagram only. But in order to carry out an extensive programme of notebook work such as the one suggested, it will be necessary to economize time in as many other ways as possible. The making of lists and the writing out of summaries can be done in odd moments. Accounts of experiments should be written as far as possible directly into the notebooks at the time the experiments are performed. Notebook work will thus be going on intermittently throughout all science lessons, and it should only occasionally be necessary to set aside a whole lesson period exclusively for this branch of the work.

## Summary of Suggestions.

To sum up, we have suggested three kinds of notebooks, (i) a class question book, (ii) a class scrapbook, (iii) a pupil's notebook.

For the pupil's notebook, we have suggested three chief kinds of entries: (i) lists of examples, (ii) accounts of important experiments, (iii) summaries of knowledge. The pupils can from the start make the first kind of entry without help. They need help and training in describing experiments, but they should, from an early stage, have opportunities for unaided work; in the Second Year most of the entries of type (ii) can then be done with little or no help. But even in the Third Year, there will be some abnormal circumstances—backward pupils or classes, specially difficult experiments—when recourse may profitably be had to devices of earlier times. The pupils will, as a general rule, need help throughout the course in making entries of type (iii), although in the Third Year the brighter pupils may well be set to make their own summaries. As a means of giving help in note-making, the completion method is recommended as generally preferable to transcription or dictation.

Whatever methods be adopted, it is important to recognize that the making of science notes is an art which cannot be acquired except by special *ad hoc* training. It is true that specific lessons in English will help; indeed, the direct help of the English teacher should be enlisted. Suitable topics for composition, for five-minute lectures, and for debates may, for example, be suggested. But science teachers, we submit, should shoulder the main responsibility for developing facility in expression (both oral and written) in connexion with their own subject.

**Books for Reference:**

*The Writing of Clear English. A Book for Students of Science and Technology*, F. W. Westaway (Blackie).

*Hints on Notemaking in Science and Mathematics*, R. T. Hughes (Bell).

*Some Suggestions for the Teaching of English in Secondary Schools in England: Appendix II, English and Science* (H.M.S.O.).

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## CHAPTER X

# Thinking

In the three previous chapters, we have discussed the chief means which are at the disposal of teachers and pupils for teaching and learning science—observing, experimenting, talking, reading, and writing. In every instance, we have emphasized the importance of using these means in such a way as to stimulate the pupils to think. Thus we have maintained that, in order to make practical work effective, pupils must be given a clear realization of its purpose before they begin; we have suggested that most of the talking in science lessons should be of the nature of discussions or conversations; and we have suggested methods of training pupils to write notes so that they are not relieved of the necessity of thinking, as they are if notes are merely dictated or transcribed.

In the first six chapters, we have discussed the selection and arrangement of subject-matter. There again the underlying idea was the same, the importance of stimulating the pupils to think. Thus we suggested that scientific topics should be chosen and approached in such a way as to make an appeal to the natural interests of the pupils; that they should be arranged in a coherent whole so that pupils, instead of being bewildered, may be able to grasp the relations between all the various items.

Our argument is that the whole process of teaching science —the selecting, arranging, approaching, presenting, and revising of the subject-matter—should be designed in such a way as to stimulate thought. In saying this, we are not making a unique claim for science; it would be true in some measure of most, if not all, other subjects of the curriculum. But the development of science does exhibit in a particularly clear way how valid conclusions can be reached.

## Scientific Method.

Men of science have, by long experience, crystallized out the essentials of the art of thinking, and they have helped to make clear the pitfalls to be avoided. They have developed a special technique called scientific method. The essentials of this method may be summarized in four stages:

(i) Appreciation of a problem to be solved.
(ii) Collection of adequate relevant data.
(iii) Formulation of a hypothesis.
(iv) Testing of the hypothesis.

So important has this technique become in modern life that it has sometimes been argued that the aim of science teachers should be to teach scientific method; some have gone farther and have argued that the real work of science teachers is to train scientific minds. This doctrine is dangerous because it gives rise to the corollary that in science it does not matter what we teach so long as it exemplifies scientific method. Accordingly, many courses have restricted pupils to dull and tedious quantitative work in a very narrow field. This policy defeats its own ends. The pupils become bored and, although they may learn in an abstract way what scientific method is, they never really understand it. Consequently, they may learn neither science nor scientific method.

The doctrine that science teachers can train scientific minds is fallacious. Even if they are successful in training pupils to think scientifically about problems of science in a science room, it does not follow that these pupils will carry over this method to other types of problems. It is notorious that men of science themselves do not display in all situations those qualities of mind which they bring to bear on their scientific work. The only way of training scientific minds is by training pupils to think in all branches of their school life; it cannot be done solely by a special course given by science teachers.

We return, therefore, to the position we took up in Chapter I.

The fundamental reason for teaching science is to increase the pupils' intellectual interest in life; the chief aim of science teachers should be to teach science. This does not mean, however, that scientific method should be neglected; on the contrary, in proportion as science is well taught, so will pupils gradually acquire clear ideas of the meaning and importance of scientific method. But the pace should not be forced. The premature teaching of technique is one of the major pedagogic sins, and scientific method, like the technique of other subjects, should be taught gradually as it is required. It is not a possession which must be given to children in order to make them fit to embark on a course of science; it is rather a possession which should come to them as a result of having taken a course. In this chapter, we shall consider how science teachers can help children to appreciate scientific method; in other words, how they can help children to discipline their thinking.

## Jumping to Conclusions.

In the first place, let us get rid of one superstition in regard to the so-called scientific mind—the superstition that men of science do not jump to conclusions. Men of science are human beings and as such they include men of various temperaments. Some are doubtless more cautious than others, and perhaps a cautious temperament is an asset in the pursuit of science. But the fact remains that as Faraday has told us, " not a tenth of the suggestions, the hopes, the wishes, the preliminary conclusions of a scientific investigator have been realized ". The same is bound to be true of children in a greater degree, and teachers of science who stimulate their pupils to think must be prepared to hear them jump to many hasty conclusions which on the evidence before them are not justified. It may be a sign of courageous imaginative thinking and a wise teacher will not repress it. The defect, especially among children, does not lie so much in jumping to conclusions as in neglecting to test these conclusions.

This is one of the most important lessons in thinking which science teachers can drive home, and opportunities of various kinds occur throughout the course.

One important occasion is when pupils jump to a conclusion from evidence which is obviously insufficient. The most convincing type of example is one in which their conclusion is wrong, and where, moreover, it is possible to demonstrate its falsity clearly by a simple experiment. For example, on seeing a little fresh air bubbled through lime-water, beginners conclude that fresh air contains no carbon dioxide. After a short discussion, the experiment is continued for about ten minutes, and the truth is discovered. A less convincing but nevertheless important type of example is one in which pupils jump to correct conclusions from insufficient evidence. For example, many of them will be ready to jump to a general conclusion after seeing one person breathe into lime-water. They should be asked immediately, "How do you know that everyone's breath is the same?" More cases are tried and the original conclusion appears to be correct. Finally, the pupils must be told that as a matter of fact it is correct. The correcting or confirming of conclusions must obviously be done tactfully and with good humour, so that pupils' interest and confidence are maintained. It is unwise to labour the point in connexion with any single example; in fact, in many instances, all that can be done is to give a word of warning that the evidence they have seen is very little, and then to tell them frankly that as a matter of fact their conclusion is correct.

A great deal must necessarily be told to children in science lessons; in many cases, experimental work in school can only point the way to probable truth. There is no harm in this, so long as it is made clear to children how much or how little they have really discovered. Teachers of science should adopt a high standard of intellectual honesty; if they do so, it will often be necessary to conclude a piece of work, not by triumphantly declaring, "We have discovered . . ." but by humbly saying, " Men of science tell us . . ." or " As a matter of fact, the truth is . . .". The following quotations from the Pupils' Books illustrate this important principle:

(*a*) Is there any air in water for fish to breathe?
Heat a flask of tap water. Observe whether any bubbles of gas are given off *before* the water boils.
The experiment shows you that water does contain gas. As a matter of fact, the bubbles you saw consist of the same gases as the air around us. (*E.G.S. I*, pp. 14–15.)

(*b*) The result of the experiment you have done seems to show that, so far from magnesium losing anything when it burns, it actually gains something. Chemists have found that this always happens when things burn—they gain something. (*E.G.S. II*, pp. 7–8.)

## Errors of Experiment.

It is important not to pretend that an experiment gives a more accurate result than it actually does. For example, when the water displaced by a toy ship is measured in cubic centimetres, the number is never found (except by chance) to be exactly equal to the number of grammes which the ship weighs. The results of several experiments do, however, point to the probable truth. In this case, the brighter pupils can arrive at the truth by a simple argument; the others must be told. It is then worth while discussing briefly why the experiment did not give accurate results (see *E.G.S. III*, pp. 119–120).

As a result of some gross error, experiments do sometimes fail to work, or they give a definitely wrong result. This should not, of course, happen frequently, and in order to guard against such mishaps beginners are advised to rehearse important experiments before demonstrating them. The actual experiments used in a science course should, moreover, be modified as a result of experience, and the most convincing ones retained, for no single textbook will contain all the most appropriate experiments for a particular teacher or school. Science teachers will find it useful to collect descriptions of new and striking experiments just as they collect new and striking information or pictures with which to illustrate their lessons. But whatever precautions are taken, mistakes are bound to occur. If a real spirit of scientific inquiry dominates the work, an occasional wrong result need cause no embarrassment. It should certainly not be " glossed over ", nor should the teacher apologize for the " wrong " result. On the contrary, it should be accepted, and then in accordance with our general principle, it should be tested by repeating the experiment, more than once if necessary. Finally, possible causes of the error should be discussed. In this way, occasional failures in experimental work may be made the basis of very valuable training in scientific method.

The device of repeating an experiment is sometimes valuable, not to dispose of a wrong result but to confirm a correct one. The following is an example which, it will be noticed, also illustrates the important technique of a control experiment:

> Fill two aluminium saucepans with cold water, and very carefully dry the outsides. Put one near the gas-stove. Put the other on the stove and light the gas. After about 5 sec., examine the bottoms of the saucepans (outside). Repeat the experiment several times. (*E.G.S. II*, p. 17.)

Another example of a similar kind of procedure may occur when a graph is being made of the rise in temperature of water as it is heated. Boiling water appears to get no hotter, and any suggestion to use two or more bunsen burners in order " to make the experiment work " should certainly be tried.

## Helping Pupils to draw Conclusions.

We have so far considered examples where pupils are apt to jump to conclusions too quickly. Sometimes, on the contrary, they find it difficult to draw any conclusion. They may, for example, be seeking the reason why hot air is lighter than cold air. They do an experiment and conclude that air expands when heated, but they can get no farther. Such an impasse is often reached at the end of a lesson period, and in order to " clear it up ", there is a temptation to give a hurried explanation. A much better policy is to send the pupils away with the problem unsolved. After an interval, there is a better chance of a successful issue to the discussion, and this is not wholly due to the fact that at the beginning of a new lesson the pupils are fresh. If in the first lesson they grasped the facts and obtained a clear idea of the problem, the interval may be a valuable incubation period even though during that time the pupils have not consciously wrestled with the problem. Real thinking requires more time than we are generally inclined to allow.

The making of inferences is often the most difficult stage in the application of scientific method. As we have suggested, the giving of time is a valuable aid. But time is not unlimited, and in science teaching it is necessary to give pupils other kinds of help. One important method, if used judiciously, is questioning. The danger of this method is illustrated by the following extreme example:

(i) If this flask full of air is heated, what will happen to the air? (It will expand.)
(ii) When it expands there will not be room for all of it. Where will some of it go? (Out of the flask.)
(iii) Will there then be less air in the flask than at first? (Yes.)
(iv) Will the hot air in the flask therefore weigh less? (Yes.)
(v) Which is lighter, the flask of cold air or the flask of hot air? (The flask of hot air.)

In this example, the essential thinking has been done by the teacher. The first answer should have been followed by questions of a more searching type, as follows:

(i) If this flask full of air is heated, what will happen to the air? (It will expand.)
(ii) What will happen then? (Some air will be driven out of the flask.)
(iii) How much air will then be in the flask? First, its volume? (A flask full.) Second, its weight? (Less than before.)

(iv) Write down and complete this sentence: A flask full of hot air . . . . . . than a . . . . . . . . .

Questioning is a useful and legitimate device, but care must be taken not to make the questions so trivial and detailed, or so suggestive, that the pupils are relieved of the necessity of thinking. In fact, whenever a conclusion has been " elicited " by questioning, it is not safe to assume that the pupils have really thought it out until we have tested whether they can restate the argument in full.

Another method of helping children to think out conclusions is by bringing together the necessary facts in a suitable order, often leaving these facts then to suggest their own questions. This is, of course, what we do when we perform experiments. The device can also be used as in the following example:

(*a*) How does carbon dioxide get into the air we breathe out? (Remember: carbon dioxide unites with a substance in the plasma and forms sodium bicarbonate; this is the same substance as baking soda; hæmoglobin unites with oxygen from the lungs and forms an acid.) (*E.G.S. II*, p. 34.)

The necessary facts are sometimes most vividly appreciated if they are arranged in the form of a graph:

(*b*) Find how hot boiling water is.

Heat some water in a kettle, or in some other suitable vessel; take the temperature of the water every minute. Record the results in a graph.

Find how hot the water is (*a*) when it begins to boil; (*b*) after it has been boiling for 5 min.; (*c*) when the water is boiling furiously. (*E.G.S. II*, p. 80.)

But when all possible help has been given—the facts clearly recalled and suitably arranged, leading questions put to suggest the relations between these facts, a generous amount of time allowed for thinking—the conclusion will neither " flash in " nor " dawn " on all the members of any class. Some pupils will learn by listening to the conclusions of others; or they will have to be told specially. It should not be imagined, however, that they have necessarily wasted their time. They have not been completely successful, but they have at least done some thinking; this has probably given them a clearer understanding of the problem and made them better able to appreciate the conclusion than if they had been wholly spoon-fed. In class teaching, one difficulty is to prevent the bright pupils from disclosing the results of their thinking before the slower ones have had a reasonable chance of finding an answer. For this reason, it is a good plan sometimes to have answers jotted down on scrap paper, and then give extra help to those who need it before adopting the last resort of plain telling.

### The Provisional Nature of Generalizations in Science.

When conclusions have been confirmed either by experiment or by telling, the fact remains that many of them are still provisional and that some of them are subject to qualification. It would, however, be pedantic when teaching children to insist on strict scientific accuracy always; we cannot make them preface every general statement by a cautionary " So far as we know at present ". In the First Year, for example, we teach them that air is a necessity for all living things. We should mention at the time that there may be exceptions to this general rule, but we ought not to blur the picture by attempting at this stage to make it absolutely correct; anerobic " breathing ", if included in a senior-school course, can well be left until the Third Year. We must be content to sketch in first the main outlines; not until these have been well mastered should accuracy of detail be attempted. It is better to give children clear ideas provisionally correct than to give them confused ideas in an attempt to be accurate to a degree beyond their comprehension. At the same time, science teachers can, by their attitude to the generalizations they teach, make it perfectly clear that the matter is not necessarily settled for ever.

## Training in Accuracy and Caution.

The suggested relaxation of the need for strict accuracy applies only to statements which are provisionally correct. It does not apply to loose statements; these should be corrected both in oral and notebook work; for example:

(*a*) What makes the clapper of the bell move forward? (Electricity.)

But here is a wire with a current of electricity flowing in it—it does not appear to make anything move? (In the bell, the electricity makes a magnet which attracts an armature. . . .) (*From a science lesson.*)

(*b*) Digestion is the process which goes on in our bodies when we are eating. (*From a science notebook.*)

By adopting a policy of using but not labouring opportunities for teaching scientific method, it is possible while pursuing a broad course of science to develop, in at least some small degree, a critical spirit. The value of caution, as we have suggested, can be taught in a variety of ways—by repeating experiments, by the use of control experiments, by looking for exceptions. Some newspaper science will provide illustrations of the need for scientific method, and pupils must often be warned against taking sensational accounts of new discoveries at their face value. Some of the debates on scientific subjects conducted in the correspondence columns provide excellent material for teaching the value of caution in connexion with the printed word.

## Arousing Emotion in Science Teaching.

It must be remembered, however, that most children are not naturally cautious, and that the first essential in the study of science is enthusiasm. It is a mistake to imagine the pursuit of science to be a cold emotionless affair, and in any case, no teaching of science in school conducted on such a theory can possibly be successful. Emotion is the driving-force behind thinking. That is why the best method of approaching particular items of science is by means of problems from the outside world. A well-chosen problem excites the child's curiosity; it arouses the emotion of wonder and he starts searching or at least groping for a solution. In other words, he begins to think. This stimulation of thought by the arousing of emotion is a necessary part of all science teaching; it is also necessary before any progress can be made in acquiring technique, for until children begin to think, we cannot begin to discipline their thinking.

We have in previous chapters made some suggestions for arousing emotion in science lessons. Thus we have emphasized the value of making science a human subject, of approaching it as a series of interesting problems, and of dwelling on its mystery and wonder. The teaching of science must not, of course, be sentimental, but there is room for an occasional exclamation, for a departure now and then from the cold language of precise scientific statement, for an appeal to the pupils' imagination. The following examples are taken from the Pupils' Books:

> (*a*) More wonderful still are the movements which growing things make in the ground. What tremendous force is necessary for a tree to push its giant roots through the hard heavy soil! And how marvellous it is that the slender thread-like roots of a plant are able, in their search for food, to tunnel their way underground! Think about these wonders of moving next time you are digging among roots in the garden. (*E.G.S. I*, p. 50.)
>
> (*b*) Try to imagine the hundreds of different pictures which are continually being thrown one after the other on to the tiny sensitive screens at the back of your eyes—still pictures and moving pictures; black and white pictures of printed pages, coloured pictures of ever-changing scenes. (*E.G.S. I*, p. 78.)

For many pupils, a feeling of wonder can be aroused by an appeal to figures:

> (*c*) When I tell you that this room holds more than one ton you will begin to think that air is something very serious. (Faraday in *The Chemical History of a Candle*.)
>
> (*d*) A man's heart weighs less than a pound, but as long as

he is alive, this wonderful little pump never stops working. Every minute it pumps at least a gallon of blood, and if the man is running quickly, it may pump eight times as much. It has been estimated that it does as much work in a year as would be sufficient to raise a ton weight from sea-level to the top of Mount Everest. (*E.G.S. II*, p. 29.)

One valuable opportunity for the stirring of emotion in connexion with science (and of course other subjects) is the school assembly. A few times each year, a special service should be held, having as its central theme either the work of some man of science or the contribution of some branch of science to human welfare. Teachers will find detailed suggestions for such services in the Books of Celebrations compiled by Dr. F. H. Hayward; services in honour of geology, biology, and astronomy are, for example, contained in *A Fourth Book of Celebrations* (Russell).

**Books for Reference:**

*The Practice of Instruction*, edited J. W. Adamson, Section VI, *Natural Science*, T. P. Nunn and C. von Wyss (National Society). (This article is particularly valuable for its treatment of hypotheses in science.)

*Scientific Method*, F. W. Westaway (Blackie).

*Discovery or the Spirit and Service of Science*, R. A. Gregory (Macmillan).

*Scientific Method in Schools*, W. H. S. Jones (Camb. Univ. Press).

## CHAPTER XI

# Special Modifications

In our discussion of the content of a science course, we have implied that all children—whether they are boys or girls, whether they live in town or country—should study the science of living. This does not mean, however, that all science courses should be identical. The process of living, though it is fundamentally the same everywhere, takes on a definitely local colour; it is influenced by the sex and by the intelligence of the pupils, by the special interests of their science teacher and by the character of the school environment. All these factors must be taken into account when a science course is being formulated, and again when methods of presenting it are being considered.

A textbook can only provide common denominator science; that is to say, it can only suggest the broad outlines of a course which is suitable for all. In order to meet the special circumstances of each individual school, many special modifications will always have to be made. Such modifications should, however, consist only of variations in sequence and emphasis and in the type of illustration. It is, to take two examples at random, unjustifiable to omit all reference to electrical energy or to the growing of plants from any school science course on account of any local circumstance. We propose in the remaining paragraphs of this chapter to consider briefly the kind of modification which may be desirable on account of important local factors.

(*a*) **Qualifications and Interests of the Science Teacher.** —Few teachers will, as a result of school and college education, be qualified in all the branches of science with which the science of living has points of contact. This fact, however, need not deter a teacher who has been trained in some of the branches of science from starting to teach such a course as we have outlined. He will at first naturally give more emphasis to those aspects of the course of which he has special knowledge than to other equally important aspects. But, once a teacher becomes biologically-minded and starts to teach the science of living, he will feel the need to study aspects of science which he has hitherto neglected. For example, the physics specialist will find it necessary to extend his study of pumps to include lungs and hearts; the chemistry specialist, teaching about oxygen, will feel the need to study the circulation of the blood and the process of carbon assimilation in plants; the biology specialist, no longer able to confine his study of moving to bones and muscles, will be led to study machinery and engines. This more extensive study of science need not in any sense be a burden, for once a teacher has grasped the framework of a coherent scheme of the science of living, he will find that each new acquisition of scientific knowledge will dovetail into this scheme in a fascinating way. Any defect in the matter of emphasis will thus tend gradually to correct itself.[1] In this connexion, it should be remembered that no one can say exactly what is the correct relative emphasis to be given to various aspects of a science course; in detail it must always remain to some extent a matter to be determined by each individual teacher.

(*b*) **Sex of the Pupils.**—The mental differences between the sexes are differences of temperament rather than of intelligence; there is no doubt that girls have the ability to study science equally with boys. Temperamental differences do, however, produce differences in interests, and despite outstanding exceptions, it is probably true to say that girls are more interested in biology than in mechanics. But if the science of living is studied, the need for choosing between biology and mechanics does not arise. Both boys and girls, for example, study the topic of moving, and in doing so they should learn something about wheels and levers, engines and electricity, and about the mysteries of muscles and growth. The desirable modifications of the course are again nothing more than differences in emphasis. Girls will probably not study electricity in as great detail as most boys, but it is wrong to assume that the subject does not interest them. And on the plane of direct utility, a little scientific knowledge about electricity will do much to dispel the prejudice against electrical appliances which is often met with among housewives; the repairing of a fuse is as easy as the trimming of a wick, but very few women trust themselves to do it. The differences in interests between boys and girls do not in any case warrant the present custom in so many schools of excluding the girls from all study of physical science and the boys from all study of biological science. The solution of the problem is to give the same general course to both sexes, with varying emphasis to meet their special interests and needs.

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[1] This optimistic view of the qualifications of teachers does not mean that we should complacently accept all the present types of science courses in secondary schools, training colleges, and universities as the best form of preparation for science teachers. But this important subject is outside the scope of the present book.

(*c*) **Interests of the Pupils.**—A teacher of a special subject is very apt to make the mistake of expecting every pupil to take a specialist interest in that subject. We have suggested (Chapter I) that scientific interest is universal among children, but this does not mean that it is or can be equally developed in everyone. Very young children show two types of interest —the scientific and the artistic. The same boy will one day ask what keeps the sun up and the next day he may exclaim: "The sun is a bird, it's got wings." Both types of interest are valuable, and education should aim at keeping both alive. "Science and the humanities," it has been well said, "are the warp and woof of the fabric of modern life"; each has its own distinctive contribution to make to the fullness of life. But the fact must be faced that for some reason, connected probably with temperament and early experiences, some children grow up preferring to think of the sun as Phœbus who "rides through rejoicing heaven", and who later

"'gan decline in haste
His weary wagon to the western vale";

others grow up preferring to think of the sun as a radiant globe 866,000 miles in diameter, the source of the energy which enables us to move. It is necessary for science teachers to remember that although it is reasonable to expect every pupil to show some interest in the scientific aspect of living, there will always be some who will choose other aspects as their intellectual hobbies.

(*d*) **Local Environment.**—It is sometimes argued that a science course should be based on local industries. As usually interpreted, this suggestion leads to the complete neglect of the one industry which is everywhere local and which transcends all others in importance—the industry of living; the result is that the course is unduly narrow and in some cases uninteresting in its later stages. At the same time, it would be foolish to pay no regard to the local environment. In a rural school, for example, the study of soil might well be more detailed than in a town school situated next door to a soap factory. But in neither school should soap or soil be omitted from the science course, for both play important and interesting parts in modern life wherever it is lived.

(*e*) **Intelligence of the Pupils.**—Senior schools are confronted with the very serious and difficult problem of educating dull children. This problem is most obviously seen in those schools which are large enough to organize on a multiple-track basis, for then the dull pupils are in sufficient numbers to form whole classes. Some of these pupils can only read with difficulty, and they are only capable of the simplest form of original composition. A special programme is obviously necessary. It need not, however, be excessively narrow. Science, dealing directly as it does with their daily lives, is a very suitable subject for dull pupils, but the general course outlined will have to be drastically and sympathetically modified. Because dull children learn slowly, it is sometimes thought necessary to allow them to spend the three years in doing, say, the First Year course. This is a mistake. There are, in the suggested First Year course, many theoretic details such as the law of moments and the measurement of work which will always be beyond the comprehension of very dull pupils; there are in the Third Year course many practical details such as bicycle pumps and electro-magnets well within their range. Dull children may be able to do only one-third of the work which average children can do, but the necessary modification of the course does not consist in giving them the first third slowly; it consists rather in choosing the most suitable third from the whole course. Quantitative work may have to be ruthlessly excluded; theoretic detail must be omitted, and much of the work must be observational and descriptive as in the junior-school stage; five-minute lectures may become one-minute talks; notebook exercises will have to be short, and instead of original compositions it may be necessary to rest content with original sentences. The ordinary course must be shorn of many of its details and much of its intricacy, but its coherence and comprehensiveness should be as far as possible retained.

This is necessarily a very inadequate treatment of the problem of teaching science to dull children. It is important, however, not to magnify the difficulties and particularly not to treat dull children as if they were a different species from average children. The difference is not one of kind but of degree. Accordingly, all that is needed is perhaps a more radical interpretation of exactly the same general principles as we have already suggested for the teaching of science to average children.

## CHAPTER XII

## Conclusion

We have in this book advocated a very comprehensive course of science having points of connexion with astronomy, biology, chemistry, geology, and physics. We have further made suggestions for a large number of activities in connexion with its study, and we have insisted on the importance in all this work of giving the pupils time and opportunity to think.

**Summary of Suggestions for Economizing Time.**

In tackling such a comprehensive and varied programme, senior schools are confronted with many difficulties, the chief of which is the limited time available. With this in mind, we have in previous chapters made various suggestions which will help teachers to economize time and it may be useful to summarize them here.

(*a*) The science course should be made as coherent as possible, for a unified whole is easier to grasp than a number of unrelated elements. Furthermore, science lessons which form part of a coherent scheme tend to reinforce one another. (See pp. 72–3.)

(*b*) The science course of senior schools should be a development of the study of Nature done in junior schools. A great deal of nature knowledge can then be caught up and woven into the pattern of the senior-school course; this will take less time than if all the necessary new facts have to be taught after the age of eleven. (See p. 8.)

(*c*) The backbone of a science course is observation and experiment, and such work necessarily consumes a great deal of time. But time can nevertheless be economized either directly or indirectly in the following ways:

(i) Pupils should be given a clear realization of the purpose of each piece of experimental work before it is begun. (See p. 80.)

(ii) Much of the teaching should be done by demonstration experiments. (See pp. 84–6.)

(iii) The apparatus used should be as simple as possible so that some pupils at least can repeat experiments at home. (See pp. 88–9.)

(iv) Very little detailed quantitative work need be done; those formal exercises in measurement which are useful and interesting should be done in mathematics lessons. (See pp. 12–13.)

(v) Experiments done by individuals should be graded or selected to suit the ability of the pupils. (See pp. 87–8.)

(vi) It is not necessary or desirable to try to teach every item in the science course by means of experiments; reading and narration are sometimes legitimate methods. (See pp. 92 ff.)

(*d*) The pupils should receive help in the writing of notes so that time is not wasted on the laborious writing of notes which when done are of very little value. (See pp. 99 ff.)

(*e*) Notes should, as a rule, be written directly into the notebooks; diagrams should be small and, as a rule, they should be drawn free-hand. (See p. 115.)

(*f*) It is not necessary to write full descriptions of every experiment done. (See pp. 110–111.)

(*g*) Though all children take the same general course, the detailed work expected of individuals should vary according to their interests and abilities. (See pp. 131–2.)

### Science and the Time-table.

It is now generally recommended that 90 minutes weekly should be the minimum time devoted to science in senior schools. As experience is gained, it is probable that many schools will find it both desirable and possible to increase the time beyond this minimum. When considering this question, the following factors should be carefully weighed:

(*a*) The curriculum of a senior school consists of the study of one topic, Living. For convenience, this may be divided broadly into four sections: (i) Arts and Crafts, (ii) Humanities (as usually understood), (iii) Physical Training, (iv) Science (including Mathematics). Time-tables should be considered and analysed with this fundamental idea in mind. Two questions germane to our present discussion then arise: Does section (iv) receive its fair proportion of time, and is this time fairly divided between the study of the two aspects of living, the scientific and the mathematical? If we take into account the time usually given to mathematics and then consider the interests, the abilities and the real intellectual and practical needs of senior-school pupils, only one answer can be given to the second of these questions.

(*b*) Much of the work suggested in the kind of programme outlined consists of spoken and written English of a very practical and purposeful kind.

(*c*) The important subject of hygiene is an integral part of any science scheme arranged in accordance with the principles advocated in this book.

## The Importance of Science.

When everything has been done to give science its due share of time and to use that time economically, many difficulties will still remain in every senior school. In the words of a recent official pamphlet, these schools "are attempting, with practically no experience as a guide, what is a revolution in educational practice".[1] It is hoped that the general principles expounded in this book, together with the detailed suggestions contained in the Pupils' Books, may prove of some service to teachers in their efforts to work out satisfactory solutions.

Finally, it is necessary to get a true appreciation not only of the difficulty but also of the importance of the problem we have been discussing. Senior schools are attempting to give average children, who, it must be remembered, constitute the great majority of our adolescent school population, some glimpse of the process of living in its various aspects. This topic—Living—should be not merely the centre of the science course, it should be the centre of the whole school curriculum. Fundamentally, the staff of a school are all teaching the same subject, but from different points of view.

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[1] *Science in Senior Schools*, Board of Education, Educational Pamphlets, No. 89 (H.M.S.O.).

Looked at in this way, science is seen in its proper relation to other subjects and in its proper perspective. The science room is not a place where pupils merely learn some interesting but isolated facts about such things as lungs, levers, and lenses; it is rather a place where they learn how all such diverse things fit into one great scheme in the process of living. The science teacher, equally with his other specialist colleagues, has an important contribution to make to each pupil's view of life.

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